

The following situations illustrate examples that may require special procedures:

(i) Your engine cannot operate on the specified duty cycle. In this case, tell us in writing why you cannot satisfactorily test your engine using this part's procedures and ask to use a different approach.

(ii) Your electronic control module requires specific input signals that are not available during dynamometer testing. In this case, tell us in writing what signals you will simulate, such as vehicle speed or transmission signals, and explain why these signals are necessary for representative testing.

(3) In a given model year, you may use procedures required for later model year engines without request. If you upgrade your testing facility in stages, you may rely on a combination of procedures for current and later model year engines as long as you can ensure, using good engineering judgment, that the combination you use for testing does not affect your ability to show compliance with the applicable emission standards.

(4) In a given model year, you may ask to use procedures allowed for earlier model year engines. We will approve this only if you show us that using the procedures allowed for earlier model years does not affect your ability to show compliance with the applicable emission standards.

(5) You may ask to use emission data collected using other procedures, such as those of the California Air Resources Board or the International Organization for Standardization. We will approve this only if you show us that using these other procedures does not affect your ability to show compliance with the applicable emission standards.

(6) During the 12 months following the effective date of any change in the provisions of this part 1065, you may ask to use data collected using procedures specified in the previously applicable version of this part 1065. This paragraph (c)(6) does not restrict the use of carryover certification data otherwise allowed by the standard-setting part.

(7) You may request to use alternate procedures that are equivalent to allowed procedures, or more accurate or more precise than allowed procedures. You may request to use a particular device or method for laboratory testing even though it was originally designed for field testing. The following provisions apply to requests for alternate procedures:

(i) *Applications.* Follow the instructions in § 1065.12.

(ii) *Submission.* Submit requests in writing to the Designated Compliance Officer.

(iii) *Notification.* We may approve your request by telling you directly, or we may issue guidance announcing our approval of a specific alternate procedure, which would make additional requests for approval unnecessary.

(d) If we require you to request approval to use other procedures under paragraph (c) of this section, you may not use them until we approve your request.

§ 1065.12 Approval of alternate procedures.

(a) To get approval for an alternate procedure under § 1065.10(c), send the Designated Compliance Officer an initial written request describing the alternate procedure and why you believe it is equivalent to the specified procedure. We may approve your request based on this information alone, or, as described in this section, we may ask you to submit to us in writing supplemental information showing that your alternate procedure is consistently and reliably at least as accurate and repeatable as the specified procedure.

(b) We may make our approval under this section conditional upon meeting other requirements or specifications. We may limit our approval, for example, to certain time frames, specific duty cycles, or specific emission standards. Based upon any supplemental information we receive after our initial approval, we may amend a previously approved alternate procedure to extend, limit, or discontinue its use. We intend to publicly announce alternate procedures that we approve.

(c) Although we will make every effort to approve only alternate procedures that completely meet our requirements, we may revoke our approval of an alternate procedure if new information shows that it is significantly not equivalent to the specified procedure.

If we do this, we will grant time to switch to testing using an allowed procedure, considering the following factors:

(1) The cost, difficulty, and availability to switch to a procedure that we allow.

(2) The degree to which the alternate procedure affects your ability to show that your engines comply with all applicable emission standards.

(3) Any relevant factors considered in our initial approval.

(d) If we do not approve your proposed alternate procedure based on the information in your initial request,

we may ask you to send the following information to fully evaluate your request:

(1) *Theoretical basis.* Give a brief technical description explaining why you believe the proposed alternate procedure should result in emission measurements equivalent to those using the specified procedure. You may include equations, figures, and references. You should consider the full range of parameters that may affect equivalence. For example, for a request to use a different NO_x measurement procedure, you should theoretically relate the alternate detection principle to the specified detection principle over the expected concentration ranges for NO, NO₂, and interference gases. For a request to use a different PM measurement procedure, you should explain the principles by which the alternate procedure quantifies particulate mass similarly to the specified procedures. For any proportioning or integrating procedure, such as a partial-flow dilution system, you should compare the alternate procedure's theoretical response to the expected response of the specified procedures.

(2) *Technical description.* Describe briefly any hardware or software needed to perform the alternate procedure. You may include dimensioned drawings, flowcharts, schematics, and component specifications. Explain any necessary calculations or other data manipulation.

(3) *Procedure execution.* Describe briefly how to perform the alternate procedure and recommend a level of training an operator should have to achieve acceptable results.

Summarize the installation, calibration, operation, and maintenance procedures in a step-by-step format. Describe how any calibration is performed using NIST-traceable standards or other similar standards we approve. Calibration must be specified by using known quantities and must not be specified as a comparison with other allowed procedures.

(4) *Data-collection techniques.* Compare measured emission results using the proposed alternate procedure and the specified procedure, as follows:

(i) Both procedures must be calibrated independently to NIST-traceable standards or to other similar standards we approve.

(ii) Include measured emission results from all applicable duty cycles. Measured emission results should show that the test engine meets all applicable emission standards according to specified procedures.

(iii) Use statistical methods to evaluate the emission measurements,

such as those described in paragraph (e) of this section.

(e) We may give you specific directions regarding methods for statistical analysis, or we may approve other methods that you propose. Absent any other directions from us, use a t-test and an F-test calculated according to § 1065.602 to evaluate whether your proposed alternate procedure is equivalent to the specified procedure. We recommend that you consult a statistician if you are unfamiliar with these statistical tests. Perform the tests as follows:

(1) Repeat measurements for all applicable duty cycles at least seven times for each procedure. You may use laboratory duty cycles to evaluate field-testing procedures.

Be sure to include all available results to evaluate the precision and accuracy of the proposed alternate procedure, as described in § 1065.2.

(2) Demonstrate the accuracy of the proposed alternate procedure by showing that it passes a two-sided t-test. Use an unpaired t-test, unless you show that a paired t-test is appropriate under both of the following provisions:

(i) For paired data, the population of the paired differences from which you sampled paired differences must be independent. That is, the probability of any given value of one paired difference is unchanged by knowledge of the value of another paired difference. For example, your paired data would violate this requirement if your series of paired differences showed a distinct increase or decrease that was dependent on the time at which they were sampled.

(ii) For paired data, the population of paired differences from which you sampled the paired differences must have a normal (i.e., Gaussian) distribution. If the population of paired difference is not normally distributed, consult a statistician for a more appropriate statistical test, which may include transforming the data with a mathematical function or using some kind of non-parametric test.

(3) Show that t is less than the critical t value, t_{crit} , tabulated in § 1065.602, for the following confidence intervals:

(i) 90% for a proposed alternate procedure for laboratory testing.

(ii) 95% for a proposed alternate procedure for field testing.

(4) Demonstrate the precision of the proposed alternate procedure by showing that it passes an F-test. Use a set of at least seven samples from the reference procedure and a set of at least seven samples from the alternate procedure to perform an F-test. The sets must meet the following requirements:

(i) Within each set, the values must be independent. That is, the probability of any given value in a set must be unchanged by knowledge of another value in that set. For example, your data would violate this requirement if a set showed a distinct increase or decrease that was dependent upon the time at which they were sampled.

(ii) For each set, the population of values from which you sampled must have a normal (i.e., Gaussian) distribution. If the population of values is not normally distributed, consult a statistician for a more appropriate statistical test, which may include transforming the data with a mathematical function or using some kind of non-parametric test.

(iii) The two sets must be independent of each other. That is, the probability of any given value in one set must be unchanged by knowledge of another value in the other set. For example, your data would violate this requirement if one value in a set showed a distinct increase or decrease that was dependent upon a value in the other set. Note that a trend of emission changes from an engine would not violate this requirement.

(iv) If you collect paired data for the paired t-test in paragraph (e)(2) in this section, use caution when selecting sets from paired data for the F-test. If you do this, select sets that do not mask the precision of the measurement procedure. We recommend selecting such sets only from data collected using the same engine, measurement instruments, and test cycle.

(5) Show that F is less than the critical F value, F_{crit} , tabulated in § 1065.602. If you have several F-test results from several sets of data, show that the mean F-test value is less than the mean critical F value for all the sets. Evaluate F_{crit} , based on the following confidence intervals:

(i) 90% for a proposed alternate procedure for laboratory testing.

(ii) 95% for a proposed alternate procedure for field testing.

§ 1065.15 Overview of procedures for laboratory and field testing.

This section outlines the procedures to test engines that are subject to emission standards.

(a) In the standard-setting part, we set brake-specific emission standards in g/(kW-hr) (or g/(hp-hr)), for the following constituents:

(1) Total oxides of nitrogen, NO_x .

(2) Hydrocarbons (HC), which may be expressed in the following ways:

(i) Total hydrocarbons, THC.

(ii) Nonmethane hydrocarbons, NMHC, which results from subtracting methane (CH_4) from THC.

(iii) Total hydrocarbon-equivalent, THCE, which results from adjusting THC mathematically to be equivalent on a carbon-mass basis.

(iv) Nonmethane hydrocarbon-equivalent, NMHCE, which results from adjusting NMHC mathematically to be equivalent on a carbon-mass basis.

(3) Particulate mass, PM.

(4) Carbon monoxide, CO.

(b) Note that some engines are not subject to standards for all the emission constituents identified in paragraph (a) of this section.

(c) We set brake-specific emission standards over test intervals, as follows:

(1) *Engine operation.* Engine operation is specified over a test interval. A test interval is the time over which an engine's total mass of emissions and its total work are determined. Refer to the standard-setting part for the specific test intervals that apply to each engine. Testing may involve measuring emissions and work during the following types of engine operation:

(i) *Laboratory testing.* Under this type of testing, you determine brake-specific emissions for duty-cycle testing by using an engine dynamometer in a laboratory. This typically consists of one or more test intervals, each defined by a duty cycle, which is a sequence of speeds and torques that an engine must follow. If the standard-setting part allows it, you may also simulate field testing by running on an engine dynamometer in a laboratory.

(ii) *Field testing.* This type of testing consists of normal in-use engine operation while an engine is installed in a vehicle. The standard-setting part specifies how test intervals are defined for field testing.

(2) *Constituent determination.* Determine the total mass of each constituent over a test interval by selecting from the following methods:

(i) *Continuous sampling.* In continuous sampling, measure the constituent's concentration continuously from raw or dilute exhaust. Multiply this concentration by the continuous (raw or dilute) flow rate at the emission sampling location to determine the constituent's flow rate. Sum the constituent's flow rate continuously over the test interval. This sum is the total mass of the emitted constituent.

(ii) *Batch sampling.* In batch sampling, continuously extract and store a sample of raw or dilute exhaust for later measurement. Extract a sample proportional to the raw or dilute exhaust flow rate. You may extract and store a proportional sample of exhaust in an appropriate container, such as a

bag, and then measure HC, CO, and NO_x concentrations in the container after the test interval. You may deposit PM from proportionally extracted exhaust onto an appropriate substrate, such as a filter. In this case, divide the PM by the amount of filtered exhaust to calculate the PM concentration. Multiply batch sampled concentrations by the total (raw or dilute) flow from which it was extracted during the test interval. This product is the total mass of the emitted constituent.

(iii) *Combined sampling.* You may use continuous and batch sampling simultaneously during a test interval, as follows:

(A) You may use continuous sampling for some constituents and batch sampling for others.

(B) You may use continuous and batch sampling for a single constituent, with one being a redundant measurement. See § 1065.201 for more information on redundant measurements.

(3) *Work determination.* Determine work over a test interval by one of the following methods:

(i) *Speed and torque.* For laboratory testing, synchronously multiply speed and brake torque to calculate instantaneous values for engine brake power. Sum engine brake power over a test interval to determine total work.

(ii) *Fuel consumed and brake-specific fuel consumption.* Directly measure fuel consumed or calculate it with chemical balances of the fuel, intake air, and exhaust. To calculate fuel consumed by

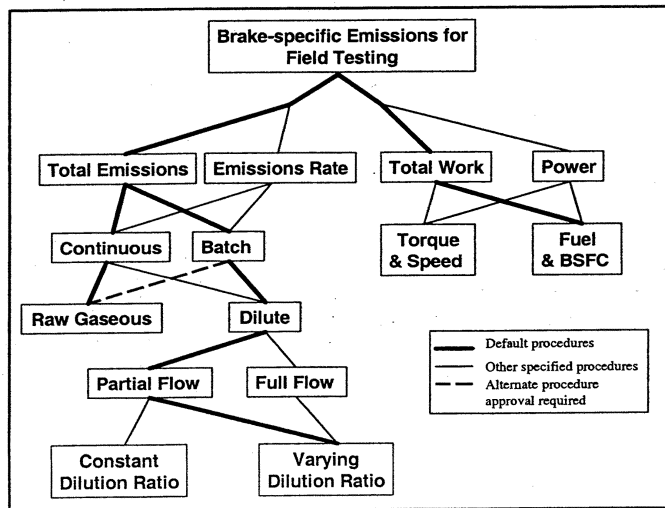
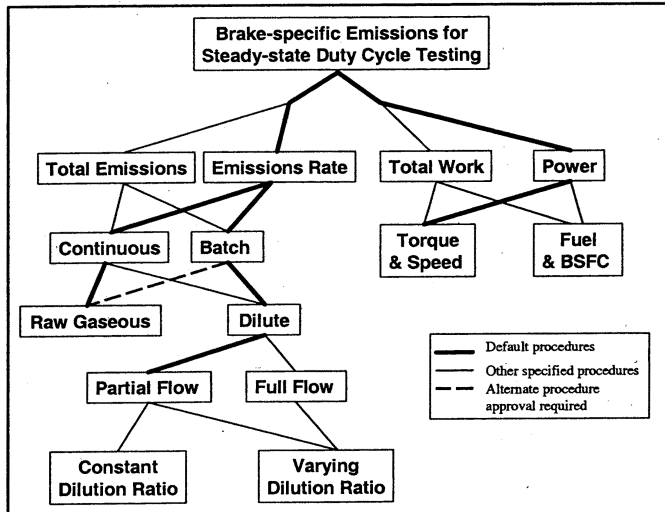
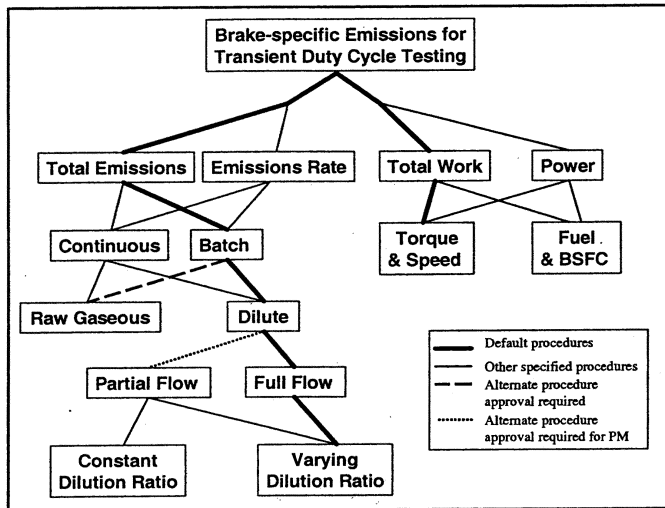
a chemical balance, you must also measure either intake-air flow rate or exhaust flow rate. Divide the fuel consumed during a test interval by the brake-specific fuel consumption to determine work over the test interval. For laboratory testing, calculate the brake-specific fuel consumption using fuel consumed and speed and torque over a test interval. For field testing, refer to the standard-setting part and § 1065.915 for selecting an appropriate value for brake-specific fuel consumption.

(d) Refer to § 1065.650 for calculations to determine brake-specific emissions.

(e) The following figure illustrates the allowed measurement configurations described in this part 1065:

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Figure 1 of §1065.15—Default test procedures and other specified procedures.



§ 1065.20 Units of measure and overview of calculations.

(a) *System of units.* The procedures in this part generally follow the International System of Units (SI), as detailed in NIST Special Publication 811, 1995 Edition, "Guide for the Use of the International System of Units (SI)," which we incorporate by reference in § 1065.1010. This document is available on the Internet at <http://physics.nist.gov/Pubs/SP811/contents.html>. Note the following exceptions:

(1) We designate rotational frequency, f_n , of an engine's crankshaft in revolutions per minute (rev/min), rather than the SI unit of reciprocal seconds (1/s). This is based on the commonplace use of rev/min in many engine dynamometer laboratories. Also, we use the symbol f_n to identify rotational frequency in rev/min, rather than the SI convention of using n . This avoids confusion with our usage of the symbol n for a molar quantity.

(2) We designate brake-specific emissions in grams per kilowatt-hour (g/(kW-hr)), rather than the SI unit of grams per megajoule (g/MJ). This is based on the fact that engines are generally subject to emission standards expressed in g/kW-hr. If we specify engine standards in grams per horsepower-hour (g/(hp-hr)) in the standard-setting part, convert units as specified in paragraph (d) of this section.

(3) We designate temperatures in units of degrees Celsius (°C) unless a calculation requires an absolute temperature. In that case, we designate temperatures in units of Kelvin (K). For conversion purposes throughout this part, 0 °C equals 273.15 K.

(b) *Concentrations.* This part does not rely on amounts expressed in parts per million or similar units. Rather, we express such amounts in the following SI units:

(1) For ideal gases, $\mu\text{mol/mol}$, formerly ppm (volume).

(2) For all substances, $\mu\text{m}^3/\text{m}^3$, formerly ppm (volume).

(3) For all substances, mg/kg, formerly ppm (mass).

(c) *Absolute pressure.* Measure absolute pressure directly or calculate it as the sum of atmospheric pressure plus a differential pressure that is referenced to atmospheric pressure.

(d) *Units conversion.* Use the following conventions to convert units:

(1) *Testing.* You may record values and perform calculations with other

units. For testing with equipment that involves other units, use the conversion factors from NIST Special Publication 811, as described in paragraph (a) of this section.

(2) *Humidity.* In this part, we identify humidity levels by specifying dewpoint, which is the temperature at which pure water begins to condense out of air. Use humidity conversions as described in § 1065.645.

(3) *Emission standards.* If your standard is in g/(hp-hr) units, convert kW to hp before any rounding by using the conversion factor of 1 hp (550 ft-lbf/s) = 0.7456999 kW. Round the final value for comparison to the applicable standard.

(e) *Rounding.* Unless the standard-setting part specifies otherwise, round only final values, not intermediate values. Round values to the number of significant digits necessary to match the number of decimal places of the applicable standard or specification. For information not related to standards or specifications, use good engineering judgment to record the appropriate number of significant digits.

(f) *Interpretation of ranges.* In this part, we specify ranges such as " $\pm 10\%$ of maximum pressure", "(40 to 50) kPa", or "(30 \pm 10) kPa". Interpret a range as a tolerance unless we explicitly identify it as an accuracy, repeatability, linearity, or noise specification. See § 1065.1001 for the definition of Tolerance.

(g) *Scaling of specifications with respect to a standard.* Because this part 1065 is applicable to a wide range of engines and emission standards, some of the specifications in this part are scaled with respect to an engine's emission standard or maximum power. This ensures that the specification will be adequate to determine compliance, but not overly burdensome by requiring unnecessarily high-precision equipment. Many of these specifications are given with respect to a "flow-weighted mean" that is expected at the standard. Flow-weighted mean is the mean of a quantity after it is weighted proportional to a corresponding flow rate. For example, if a gas concentration is measured continuously from the raw exhaust of an engine, its flow-weighted mean concentration is the sum of the products of each recorded concentration times its respective exhaust flow rate, divided by the sum of the recorded flow rates. As another example, the bag concentration from a CVS system is the

same as the flow-weighted mean concentration, because the CVS system itself flow-weights the bag concentration. Refer to § 1065.602 for information needed to estimate and calculate flow-weighted means.

§ 1065.25 Recordkeeping.

The procedures in this part include various requirements to record data or other information. Refer to the standard-setting part regarding recordkeeping requirements. If the standard-setting part does not specify recordkeeping requirements, store these records in any format and on any media and keep them readily available for one year after you send an associated application for certification, or one year after you generate the data if they do not support an application for certification. You must promptly send us organized, written records in English if we ask for them. We may review them at any time.

Subpart B—Equipment Specifications**§ 1065.101 Overview.**

(a) This subpart specifies equipment, other than measurement instruments, related to emission testing. The provisions of this subpart apply for all testing in laboratories. See subpart J of this part to determine which of the provisions of this subpart apply for field testing. This includes three broad categories of equipment—dynamometers, engine fluid systems (such as fuel and intake-air systems), and emission-sampling hardware.

(b) Other related subparts in this part identify measurement instruments (subpart C), describe how to evaluate the performance of these instruments (subpart D), and specify engine fluids and analytical gases (subpart H).

(c) Subpart J of this part describes additional equipment that is specific to field testing.

(d) Figures 1 and 2 of this section illustrate some of the possible configurations of laboratory equipment. These figures are schematics only; we do not require exact conformance to them. Figure 1 of this section illustrates the equipment specified in this subpart and gives some references to sections in this subpart. Figure 2 of this section illustrates some of the possible configurations of a full-flow dilution, constant-volume sampling (CVS) system. Not all possible CVS configurations are shown.

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Figure 1 of §1065.101—Engine dynamometer laboratory equipment.

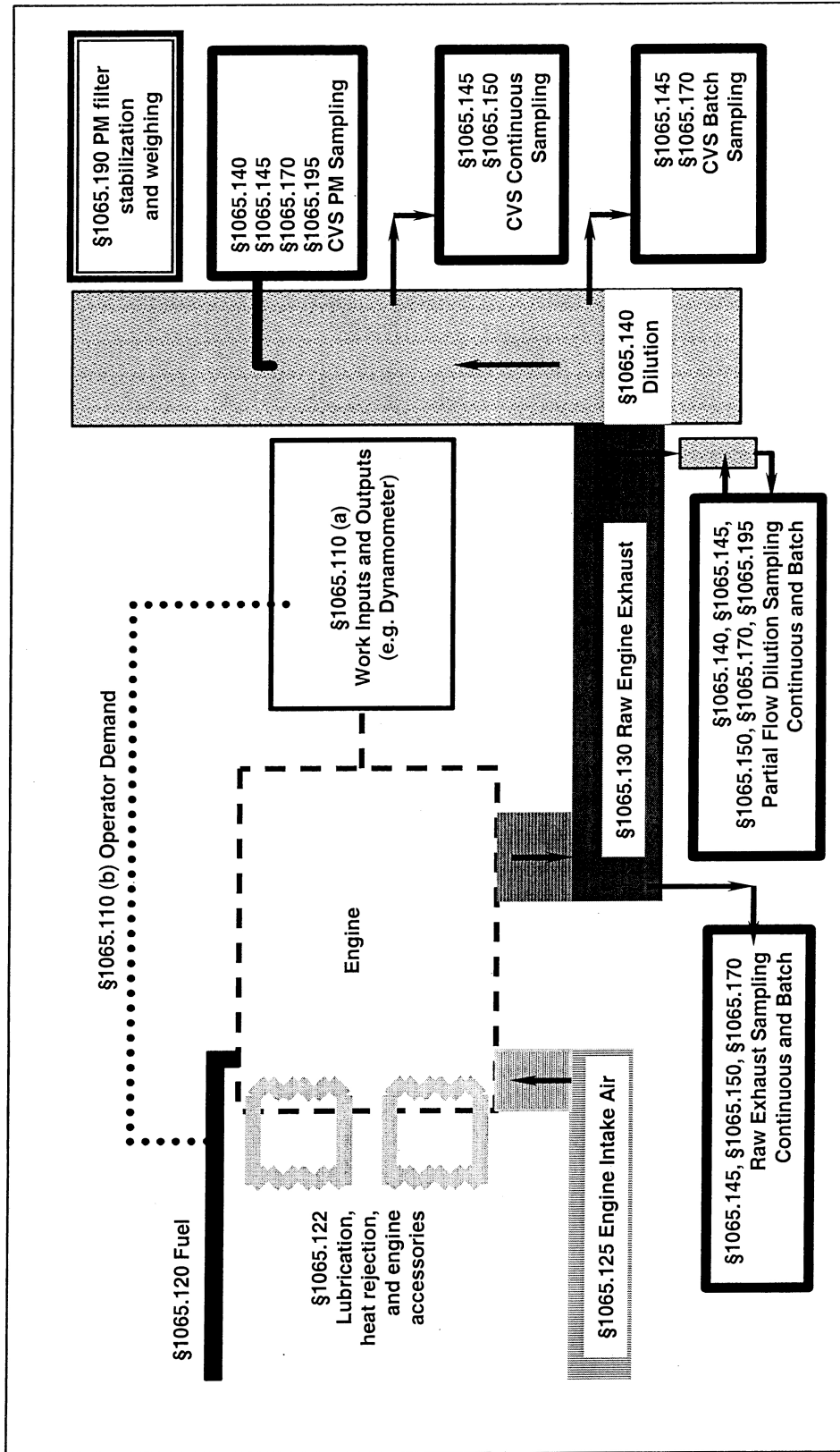
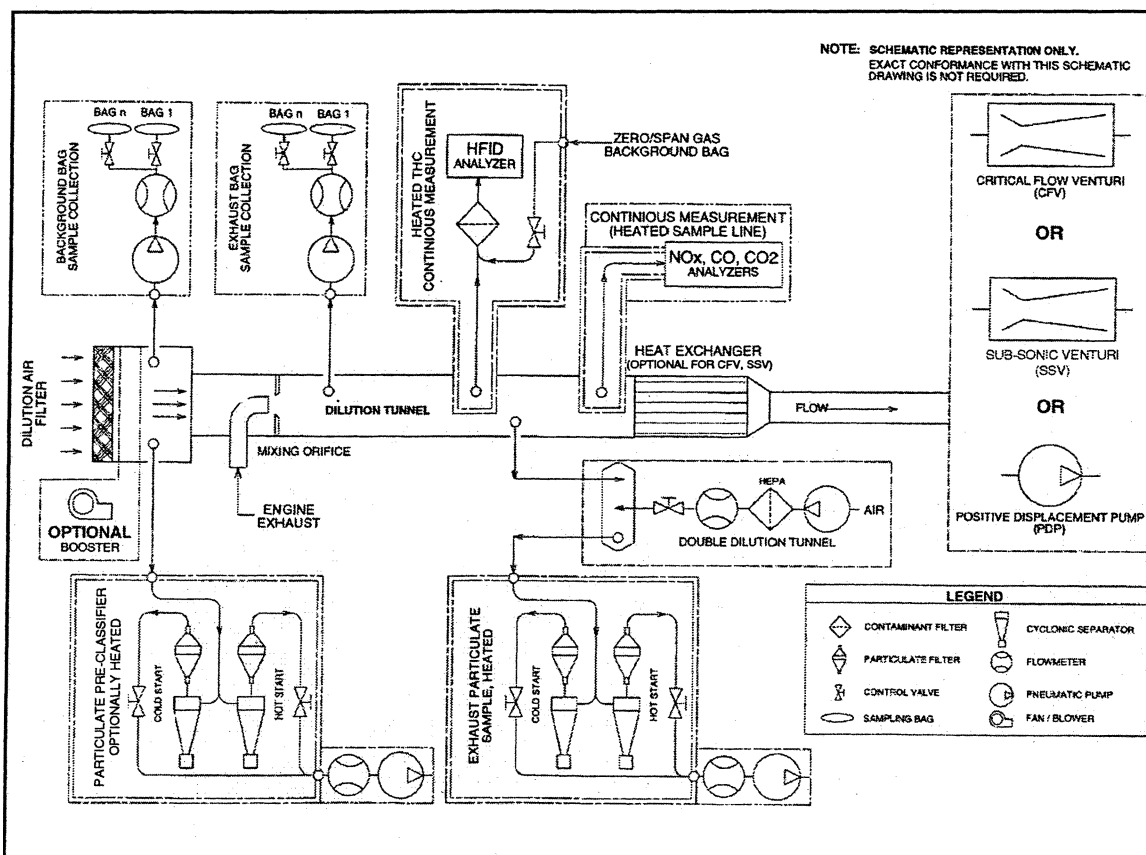


Figure 2 of §1065.101—Examples of some full-flow dilution sampling configurations.



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§ 1065.110 Work inputs and outputs, accessory work, and operator demand.

(a) *Work.* Use good engineering judgment to simulate all engine work inputs and outputs as they typically would operate in use. Account for work inputs and outputs during an emission test by measuring them; or, if they are small, you may show by engineering analysis that disregarding them does not affect your ability to determine the net work output by more than $\pm 0.5\%$ of the net reference work output over the test interval. Use equipment to simulate the specific types of work, as follows:

(1) *Shaft work.* Use an engine dynamometer that is able to meet the cycle-validation criteria in § 1065.514 over each applicable duty cycle.

(i) You may use eddy-current and water-brake dynamometers for any testing that does not involve engine motoring, which is identified by negative torque commands in a reference duty cycle. See the standard setting part for reference duty cycles that are applicable to your engine.

(ii) You may use alternating-current or direct-current motoring dynamometers for any type of testing.

(iii) You may use one or more dynamometers.

(2) *Electrical work.* Use one or more of the following to simulate electrical work:

(i) Use storage batteries or capacitors that are of the type and capacity installed in use.

(ii) Use motors, generators, and alternators that are of the type and capacity installed in use.

(iii) Use a resistor load bank to simulate electrical loads.

(3) *Pump, compressor, and turbine work.* Use pumps, compressors, and turbines that are of the type and capacity installed in use. Use working fluids that are of the same type and thermodynamic state as normal in-use operation.

(b) *Laboratory work inputs.* You may supply any laboratory inputs of work to the engine. For example, you may supply electrical work to the engine to operate a fuel system, and as another example you may supply compressor work to the engine to actuate pneumatic

valves. We may ask you to show by engineering analysis your accounting of laboratory work inputs to meet the criterion in paragraph (a) of this section.

(c) *Engine accessories.* You must either install or account for the work of engine accessories required to fuel, lubricate, or heat the engine, circulate coolant to the engine, or to operate aftertreatment devices. Operate the engine with these accessories installed or accounted for during all testing operations, including mapping. If these accessories are not powered by the engine during a test, account for the work required to perform these functions from the total work used in brake-specific emission calculations. For air-cooled engines only, subtract externally powered fan work from total work. We may ask you to show by engineering analysis your accounting of engine accessories to meet the criterion in paragraph (a) of this section.

(d) *Engine starter.* You may install a production-type starter.

(e) *Operator demand for shaft work.* Command the operator demand and the dynamometer(s) to follow the prescribed duty cycle with set points for engine

speed and torque at 5 Hz (or more frequently) for transient testing or 1 Hz (or more frequently) for steady-state testing. Use a mechanical or electronic input to control operator demand such that the engine is able to meet the validation criteria in § 1065.514 over each applicable duty cycle. Record feedback values for engine speed and torque at 5 Hz or more frequently for evaluating performance relative to the cycle validation criteria. Using good engineering judgment, you may improve control of operator demand by altering on-engine speed and torque controls. However, if these changes result in unrepresentative testing, you must notify us and recommend other test procedures under § 1065.10(c)(1).

§ 1065.120 Fuel properties and fuel temperature and pressure.

(a) Use fuels as specified in subpart H of this part.

(b) If the engine manufacturer specifies fuel temperature and pressure tolerances and the location where they are to be measured, then measure the fuel temperature and pressure at the specified location to show that you are within these tolerances throughout testing.

(c) If the engine manufacturer does not specify fuel temperature and pressure tolerances, use good engineering judgment to set and control fuel temperature and pressure in a way that represents typical in-use fuel temperatures and pressures.

§ 1065.122 Engine cooling and lubrication.

(a) *Engine cooling.* Cool the engine during testing so its intake-air, oil, coolant, block, and head temperatures are within their expected ranges for normal operation. You may use laboratory auxiliary coolers and fans.

(1) If you use laboratory auxiliary fans you must account for work input to the fan(s) according to § 1065.110.

(2) See § 1065.125 for more information related to intake-air cooling.

(3) See § 1065.127 for more information related to exhaust gas recirculation cooling.

(4) Measure temperatures at the manufacturer-specified locations. If the manufacturer does not specify temperature measurement locations, then use good engineering judgment to monitor intake-air, oil, coolant, block, and head temperatures to ensure that they are in their expected ranges for normal operation.

(b) *Forced cooldown.* You may install a forced cooldown system for an engine and an exhaust aftertreatment device according to § 1065.530(a)(1).

(c) *Lubricating oil.* Use lubricating oils specified in § 1065.740.

(d) *Coolant.* For liquid-cooled engines, use coolant as specified in § 1065.745.

§ 1065.125 Engine intake air.

(a) Use the intake-air system installed on the engine or one that represents a typical in-use configuration. This includes the charge-air cooling and exhaust gas recirculation systems.

(b) Measure temperature, humidity, and atmospheric pressure near the entrance to the engine's air filter, or at the inlet to the air intake system for engines that have no air filter. You may use a shared atmospheric pressure meter as long as your equipment for handling intake air maintains ambient pressure where you test the engine within ± 1 kPa of the shared atmospheric pressure. You may use a shared humidity measurement for intake air as long as your equipment for handling intake air maintains dewpoint where you test the engine to within $+0.5$ °C of the shared humidity measurement.

(c) Use an air-intake restriction that represents production engines. Make sure the intake-air restriction is between the manufacturer's specified maximum for a clean filter and the manufacturer's specified maximum allowed. Measure the static differential pressure of the restriction at the location and at the speed and torque set points specified by the manufacturer. If the manufacturer does not specify a location, measure this pressure upstream any turbocharger or exhaust gas recirculation system connection to the intake air system. If the manufacturer does not specify speed and torque points, measure this pressure while the engine outputs maximum power. As the manufacturer, you are liable for emission compliance for all values up to the maximum restriction you specify for a particular engine.

(d) This paragraph (d) includes provisions for simulating charge-air cooling in the laboratory. This approach is described in paragraph (d)(1) of this section. Limits on using this approach are described in paragraphs (d)(2) and (3) of this section.

(1) Use a charge-air cooling system with a total intake-air capacity that represents production engines' in-use installation. Maintain coolant conditions as follows:

(i) Maintain a coolant temperature of at least 20 °C at the inlet to the charge-air cooler throughout testing.

(ii) At maximum engine power, set the coolant flow rate to achieve an air temperature within ± 5 °C of the value specified by the manufacturer at the charge-air cooler outlet. Measure the air-outlet temperature at the location specified by the manufacturer. Use this

coolant flow rate set point throughout testing.

(2) Using a constant flow rate as described in paragraph (d)(1)(ii) of this section may result in unrepresentative overcooling of the intake air. If this causes any regulated emission to decrease, then you may still use this approach, but only if the effect on emissions is smaller than the degree to which you meet the applicable emission standards. If the effect on emissions is larger than the degree to which you meet the applicable emission standards, you must use a variable flow rate that controls intake-air temperatures to be representative of in-use operation.

(3) This approach does not apply for field testing. You may not correct measured emission levels from field testing to account for any differences caused by the simulated cooling in the laboratory.

§ 1065.127 Exhaust gas recirculation.

Use the exhaust gas recirculation (EGR) system installed with the engine or one that represents a typical in-use configuration. This includes any applicable EGR cooling devices.

§ 1065.130 Engine exhaust.

(a) *General.* Use the exhaust system installed with the engine or one that represents a typical in-use configuration. This includes any applicable aftertreatment devices.

(b) *Aftertreatment configuration.* If you do not use the exhaust system installed with the engine, configure any aftertreatment devices as follows:

(1) Position any aftertreatment device so its distance from the nearest exhaust manifold flange or turbocharger outlet is within the range specified by the engine manufacturer in the application for certification. If this distance is not specified, position aftertreatment devices to represent typical in-use vehicle configurations.

(2) You may use laboratory exhaust tubing upstream of any aftertreatment device that is of diameter(s) typical of in-use configurations. If you use laboratory exhaust tubing upstream of any aftertreatment device, position each aftertreatment device according to paragraph (b)(1) of this section.

(c) *Sampling system connections.* Connect an engine's exhaust system to any raw sampling location or dilution stage, as follows:

(1) Minimize laboratory exhaust tubing lengths and use a total length of laboratory tubing of no more than 10 m or 50 outside diameters, whichever is greater. If laboratory exhaust tubing consists of several different outside tubing diameters, count the number of

diameters of length of each individual diameter, then sum all the diameters to determine the total length of exhaust tubing in diameters. Use the mean outside diameter of any converging or diverging sections of tubing. Use outside hydraulic diameters of any noncircular sections.

(2) You may install short sections of flexible laboratory exhaust tubing at any location in the engine or laboratory exhaust systems. You may use up to a combined total of 2 m or 10 outside diameters of flexible exhaust tubing.

(3) Insulate any laboratory exhaust tubing downstream of the first 25 outside diameters of length.

(4) Use laboratory exhaust tubing materials that are smooth-walled, electrically conductive, and not reactive with exhaust constituents. Stainless steel is an acceptable material.

(5) We recommend that you use laboratory exhaust tubing that has either a wall thickness of less than 2 mm or is air gap-insulated to minimize temperature differences between the wall and the exhaust.

(d) *In-line instruments.* You may insert instruments into the laboratory exhaust tubing, such as an in-line smoke meter. If you do this, you may leave a length of up to 5 outside diameters of laboratory exhaust tubing uninsulated on each side of each instrument, but you must leave a length of no more than 25 outside diameters of laboratory exhaust tubing uninsulated in total, including any lengths adjacent to in-line instruments.

(e) *Grounding.* Electrically ground the entire exhaust system.

(f) *Forced cooldown.* You may install a forced cooldown system for an exhaust aftertreatment device according to § 1065.530(a)(1)(i).

(g) *Exhaust restriction.* Use an exhaust restriction that represents the performance of production engines. Make sure the exhaust restriction set point is either (80 to 100) % of the maximum exhaust restriction specified by the manufacturer; or if the maximum is 5 kPa or less, make sure the set point is no less than 1.0 kPa from the maximum. For example, if the maximum back pressure is 4.5 kPa, do not use an exhaust restriction set point that is less than 3.5 kPa. Measure and set this pressure at the location and at the speed, torque and aftertreatment set points specified by the manufacturer. As the manufacturer, you are liable for emission compliance for all values up to the maximum restriction you specify for a particular engine.

(h) *Open crankcase emissions.* If the standard-setting part requires measuring open crankcase emissions, you may

either measure open crankcase emissions separately using a method that we approve in advance, or route open crankcase emissions directly into the exhaust system for emission measurement as follows:

(1) Use laboratory tubing materials that are smooth-walled, electrically conductive, and not reactive with crankcase emissions. Stainless steel is an acceptable material.

Minimize tube lengths. We also recommend using heated or thin-walled or air gap-insulated tubing to minimize temperature differences between the wall and the crankcase emission constituents.

(2) Minimize the number of bends in the laboratory crankcase tubing and maximize the radius of any unavoidable bend.

(3) Use laboratory crankcase exhaust tubing that meets the engine manufacturer's specifications for crankcase back pressure.

(4) Connect the crankcase exhaust tubing into the raw exhaust downstream of any aftertreatment system, downstream of any installed exhaust restriction, and sufficiently upstream of any sample probes to ensure complete mixing with the engine's exhaust before sampling. Extend the crankcase exhaust tube into the free stream of exhaust to avoid boundary-layer effects and to promote mixing. You may orient the crankcase exhaust tube's outlet in any direction relative to the raw exhaust flow.

§ 1065.140 Dilution for gaseous and PM constituents.

(a) *General.* You may dilute exhaust with ambient air, synthetic air, or nitrogen that is at least 15 °C. Note that the composition of the diluent affects some gaseous emission measurement instruments' response to emissions. We recommend diluting exhaust at a location as close as possible to the location where ambient air dilution would occur in use.

(b) *Dilution-air conditions and background concentrations.* Before a diluent is mixed with exhaust, you may precondition it by increasing or decreasing its temperature or humidity. You may also remove constituents to reduce their background concentrations. The following provisions apply to removing constituents or accounting for background concentrations:

(1) You may measure constituent concentrations in the diluent and compensate for background effects on test results. See § 1065.650 for calculations that compensate for background concentrations.

(2) Either measure these background concentrations the same way you measure diluted exhaust constituents, or measure them in a way that does not affect your ability to demonstrate compliance with the applicable standards. For example, you may use the following simplifications for background sampling:

(i) You may disregard any proportional sampling requirements.

(ii) You may use unheated gaseous sampling systems.

(iii) You may use unheated PM sampling systems only if we approve it in advance.

(iv) You may use continuous sampling if you use batch sampling for diluted emissions.

(v) You may use batch sampling if you use continuous sampling for diluted emissions.

(3) For removing background PM, we recommend that you filter all dilution air, including primary full-flow dilution air, with high-efficiency particulate air (HEPA) filters that have an initial minimum collection efficiency specification of 99.97% (see § 1065.1001 for procedures related to HEPA-filtration efficiencies). Ensure that HEPA filters are installed properly so that background PM does not leak past the HEPA filters. If you choose to correct for background PM without using HEPA filtration, demonstrate that the background PM in the dilution air contributes less than 50% to the net PM collected on the sample filter.

(c) *Full-flow dilution; constant-volume sampling (CVS).* You may dilute the full flow of raw exhaust in a dilution tunnel that maintains a nominally constant volume flow rate, molar flow rate or mass flow rate of diluted exhaust, as follows:

(1) *Construction.* Use a tunnel with inside surfaces of 300 series stainless steel. Electrically ground the entire dilution tunnel. We recommend a thin-walled and insulated dilution tunnel to minimize temperature differences between the wall and the exhaust gases.

(2) *Pressure control.* Maintain static pressure at the location where raw exhaust is introduced into the tunnel within 1.2 kPa of atmospheric pressure. You may use a booster blower to control this pressure. If you test an engine using more careful pressure control and you show by engineering analysis or by test data that you require this level of control to demonstrate compliance at the applicable standards, we will maintain the same level of static pressure control when we test that engine.

(3) *Mixing.* Introduce raw exhaust into the tunnel by directing it downstream

along the centerline of the tunnel. You may introduce a fraction of dilution air radially from the tunnel's inner surface to minimize exhaust interaction with the tunnel walls. You may configure the system with turbulence generators such as orifice plates or fins to achieve good mixing. We recommend a minimum Reynolds number, $Re^{\#}$, of 4000 for the diluted exhaust stream, where $Re^{\#}$ is based on the inside diameter of the dilution tunnel. $Re^{\#}$ is defined in § 1065.640.

(4) *Flow measurement preconditioning.* You may condition the diluted exhaust before measuring its flow rate, as long as this conditioning takes place downstream of any sample probes, as follows:

(i) You may use flow straighteners, pulsation dampeners, or both of these.

(ii) You may use a filter.

(iii) You may use a heat exchanger to control the temperature upstream of any flow meter. Note paragraph (c)(6) of this section regarding aqueous condensation.

(5) *Flow measurement.* Section 1065.240 describes measurement instruments for diluted exhaust flow.

(6) *Aqueous condensation.* You may either prevent aqueous condensation throughout the dilution tunnel or you may measure humidity at the flow meter inlet. Calculations in § 1065.645 and § 1065.650 account for either method of addressing humidity in the diluted exhaust. Note that preventing aqueous condensation involves more than keeping pure water in a vapor phase (see § 1065.1001).

(7) *Flow compensation.* Maintain nominally constant molar, volumetric or mass flow of diluted exhaust. You may maintain nominally constant flow by either maintaining the temperature and pressure at the flow meter or by directly controlling the flow of diluted exhaust. You may also directly control the flow of proportional samplers to maintain proportional sampling. For an individual test, validate proportional sampling as described in § 1065.545.

(d) *Partial-flow dilution (PFD).* Except as specified in this paragraph (d), you may dilute a partial flow of raw or previously diluted exhaust before measuring emissions. § 1065.240 describes PFD-related flow measurement instruments. PFD may consist of constant or varying dilution ratios as described in paragraphs (d)(2) and (3) of this section. An example of a constant dilution ratio PFD is a "secondary dilution PM" measurement system. An example of a varying dilution ratio PFD is a "bag mini-diluter" or BMD.

(1) *Applicability.* (i) You may not use PFD if the standard-setting part prohibits it.

(ii) You may use PFD to extract a proportional raw exhaust sample for any batch or continuous PM emission sampling over any transient duty cycle only if we have explicitly approved it according to § 1065.10 as an alternative procedure to the specified procedure for full-flow CVS.

(iii) You may use PFD to extract a proportional raw exhaust sample for any batch or continuous gaseous emission sampling.

(iv) You may use PFD to extract a proportional raw exhaust sample for any batch or continuous PM emission sampling over any steady-state duty cycle or its ramped-modal cycle (RMC) equivalent.

(v) You may use PFD to extract a proportional raw exhaust sample for any batch or continuous field-testing.

(vi) You may use PFD to extract a proportional diluted exhaust sample from a CVS for any batch or continuous emission sampling.

(vii) You may use PFD to extract a constant raw or diluted exhaust sample for any continuous emission sampling.

(2) *Constant dilution-ratio PFD.* Do one of the following for constant dilution-ratio PFD:

(i) Dilute an already proportional flow. For example, you may do this as a way of performing secondary dilution from a CVS tunnel to achieve temperature control for PM sampling.

(ii) Continuously measure constituent concentrations. For example, you might dilute to precondition a sample of raw exhaust to control its temperature, humidity, or constituent concentrations upstream of continuous analyzers. In this case, you must take into account the dilution ratio before multiplying the continuous concentration by the sampled exhaust flow rate.

(iii) Extract a proportional sample from the constant dilution ratio PFD system. For example, you might use a variable-flow pump to proportionally fill a gaseous storage medium such as a bag from a PFD system. In this case, the proportional sampling must meet the same specifications as varying dilution ratio PFD in paragraph (d)(3) of this section.

(3) *Varying dilution-ratio PFD.* All the following provisions apply for varying dilution-ratio PFD:

(i) Use a control system with sensors and actuators that can maintain proportional sampling over intervals as short as 200 ms (*i.e.*, 5 Hz control).

(ii) For control input, you may use any sensor output from one or more measurements; for example, intake-air

flow, fuel flow, exhaust flow, engine speed, and intake manifold temperature and pressure.

(iii) Account for any emission transit time in the PFD system.

(iv) You may use preprogrammed data if they have been determined for the specific test site, duty cycle, and test engine from which you dilute emissions.

(v) We recommend that you run practice cycles to meet the validation criteria in § 1065.545. Note that you must validate every emission test by meeting the validation criteria with the data from that specific test, not from practice cycles or other tests.

(vi) You may not use a PFD system that requires preparatory tuning or calibration with a CVS or with the emission results from a CVS. Rather, you must be able to independently calibrate the PFD.

(e) *Dilution and temperature control of PM samples.* Dilute PM samples at least once upstream of transfer lines. You may dilute PM samples upstream of a transfer line using full-flow dilution, or partial-flow dilution immediately downstream of a PM probe. Control sample temperature to a $(47 \pm 5)^\circ\text{C}$ tolerance, as measured anywhere within 20 cm upstream or downstream of the PM storage media (such as a filter). Measure this temperature with a bare-wire junction thermocouple with wires that are (0.500 ± 0.025) mm diameter, or with another suitable instrument that has equivalent performance. Heat or cool the PM sample primarily by dilution.

§ 1065.145 Gaseous and PM probes, transfer lines, and sampling system components.

(a) *Continuous and batch sampling.* Determine the total mass of each constituent with continuous or batch sampling, as described in § 1065.15(c)(2). Both types of sampling systems have probes, transfer lines, and other sampling system components that are described in this section.

(b) *Gaseous and PM sample probes.* A probe is the first fitting in a sampling system. It protrudes into a raw or diluted exhaust stream to extract a sample, such that its inside and outside surfaces are in contact with the exhaust. A sample is transported out of a probe into a transfer line, as described in paragraph (c) of this section. The following provisions apply to probes:

(1) *Probe design and construction.* Use sample probes with inside surfaces of 300 series stainless steel or, for raw exhaust sampling, use a nonreactive material capable of withstanding raw exhaust temperatures. Locate sample

probes where constituents are mixed to their mean sample concentration. Take into account the mixing of any crankcase emissions that may be routed into the raw exhaust. Locate each probe to minimize interference with the flow to other probes. We recommend that all probes remain free from influences of boundary layers, wakes, and eddies—especially near the outlet of a raw-exhaust tailpipe where unintended dilution might occur. Make sure that purging or back-flushing of a probe does not influence another probe during testing. You may use a single probe to extract a sample of more than one constituent as long as the probe meets all the specifications for each constituent.

(2) *Gaseous sample probes.* Use either single-port or multi-port probes for sampling gaseous emissions. You may orient these probes in any direction relative to the raw or diluted exhaust flow. For some probes, you must control sample temperatures, as follows:

(i) For probes that extract NO_x from diluted exhaust, control the probe's wall temperature to prevent aqueous condensation.

(ii) For probes that extract hydrocarbons for NMHC or NMHCE analysis from the diluted exhaust of compression-ignition engines, 2-stroke spark-ignition engines, or 4-stroke spark-ignition engines below 19 kW, maintain a probe wall temperature tolerance of $(191 \pm 11)^\circ\text{C}$.

(3) *PM sample probes.* Use PM probes with a single opening at the end. Orient PM probes to face directly upstream. If you shield a PM probe's opening with a PM pre-classifier such as a hat, you may not use the preclassifier we specify in paragraph (d)(4)(i) of this section. We recommend sizing the inside diameter of PM probes to approximate isokinetic sampling at the expected mean flow rate.

(c) *Transfer lines.* You may use transfer lines to transport an extracted sample from a probe to an analyzer, storage medium, or dilution system. Minimize the length of all transfer lines by locating analyzers, storage media, and dilution systems as close to probes as practical. We recommend that you minimize the number of bends in transfer lines and that you maximize the radius of any unavoidable bend. Avoid using 90° elbows, tees, and cross-fittings in transfer lines. Where such connections and fittings are necessary, take steps, using good engineering judgment, to ensure that you meet the temperature tolerances in this paragraph (c). This may involve measuring temperature at various locations within transfer lines and fittings. You may use

a single transfer line to transport a sample of more than one constituent, as long as the transfer line meets all the specifications for each constituent. The following construction and temperature tolerances apply to transfer lines:

(1) *Gaseous samples.* Use transfer lines with inside surfaces of 300 series stainless steel, PTFE, Viton™, or any other material that you demonstrate has better properties for emission sampling. For raw exhaust sampling, use a non-reactive material capable of withstanding raw exhaust temperatures. You may use in-line filters if they do not react with exhaust constituents and if the filter and its housing meet the same temperature requirements as the transfer lines, as follows:

(i) For NO_x transfer lines upstream of either an NO_2 -to- NO converter that meets the specifications of § 1065.378 or a chiller that meets the specifications of § 1065.376, maintain a sample temperature that prevents aqueous condensation.

(ii) For THC transfer lines for testing compression-ignition engines, 2-stroke spark-ignition engines, or 4-stroke spark-ignition engines below 19 kW, maintain a wall temperature tolerance throughout the entire line of $(191 \pm 11)^\circ\text{C}$. If you sample from raw exhaust, you may connect an unheated, insulated transfer line directly to a probe. Design the length and insulation of the transfer line to cool the highest expected raw exhaust temperature to no lower than 191°C , as measured at the transfer line's outlet.

(2) *PM samples.* We recommend heated transfer lines or a heated enclosure to minimize temperature differences between transfer lines and exhaust constituents. Use transfer lines that are inert with respect to PM and are electrically conductive on the inside surfaces. We recommend using PM transfer lines made of 300 series stainless steel. Electrically ground the inside surface of PM transfer lines.

(d) *Optional sample-conditioning components for gaseous sampling.* You may use the following sample-conditioning components to prepare gaseous samples for analysis, as long you do not install or use them in a way that adversely affects your ability to show that your engines comply with all applicable gaseous emission standards.

(1) *NO_2 -to- NO converter.* You may use an NO_2 -to- NO converter that meets the efficiency-performance check specified in § 1065.378 at any point upstream of a NO_x analyzer, sample bag, or other storage medium.

(2) *Sample dryer.* You may use either type of sample dryer described in this paragraph (d)(2) to decrease the effects

of water on gaseous emission measurements. You may not use a chemical dryer, or used dryers upstream of PM sample filters.

(i) *Osmotic-membrane.* You may use an osmotic-membrane dryer upstream of any gaseous analyzer or storage medium, as long as it meets the temperature specifications in paragraph (c)(1) of this section. Because osmotic-membrane dryers may deteriorate after prolonged exposure to certain exhaust constituents, consult with the membrane manufacturer regarding your application before incorporating an osmotic-membrane dryer. Monitor the dewpoint, T_{dew} , and absolute pressure, p_{total} , downstream of an osmotic-membrane dryer. You may use continuously recorded values of T_{dew} and p_{total} in the amount of water calculations specified in § 1065.645. If you do not continuously record these values, you may use their peak values observed during a test or their alarm setpoints as constant values in the calculations specified in § 1065.645. You may also use a nominal p_{total} , which you may estimate as the dryer's lowest absolute pressure expected during testing.

(ii) *Thermal chiller.* You may use a thermal chiller upstream of some gas analyzers and storage media. You may not use a thermal chiller upstream of a THC measurement system for compression-ignition engines, 2-stroke spark-ignition engines, or 4-stroke spark-ignition engines below 19 kW. If you use a thermal chiller upstream of an NO_2 -to- NO converter or in a sampling system without an NO_2 -to- NO converter, the chiller must meet the NO_2 loss-performance check specified in § 1065.376. Monitor the dewpoint, T_{dew} , and absolute pressure, p_{total} , downstream of a thermal chiller. You may use continuously recorded values of T_{dew} and p_{total} in the emission calculations specified in § 1065.650. If you do not continuously record these values, you may use their peak values observed during a test or their high alarm setpoints as constant values in the amount of water calculations specified in § 1065.645. You may also use a nominal p_{total} , which you may estimate as the dryer's lowest absolute pressure expected during testing. If it is valid to assume the degree of saturation in the thermal chiller, you may calculate T_{dew} based on the known chiller efficiency and continuous monitoring of chiller temperature, $T_{chiller}$. If you do not continuously record values of $T_{chiller}$, you may use its peak value observed during a test, or its alarm setpoint, as a constant value to determine a constant amount of water according to

§ 1065.645. If it is valid to assume that $T_{chiller}$ is equal to T_{dew} , you may use $T_{chiller}$ in lieu of T_{dew} according to § 1065.645. If we ask for it, you must show by engineering analysis or by data the validity of any assumptions allowed by this paragraph (d)(2)(ii).

(3) *Sample pumps.* You may use sample pumps upstream of an analyzer or storage medium for any gas. Use sample pumps with inside surfaces of 300 series stainless steel, PTFE, or any other material that you demonstrate has better properties for emission sampling. For some sample pumps, you must control temperatures, as follows:

(i) If you use a NO_x sample pump upstream of either an NO₂-to-NO converter that meets § 1065.378 or a chiller that meets § 1065.376, it must be heated to prevent aqueous condensation.

(ii) For testing compression-ignition engines, 2-stroke spark-ignition engines, or 4-stroke compression ignition engines below 19 kW, if you use a THC sample pump upstream of a THC analyzer or storage medium, its inner surfaces must be heated to a tolerance of (191 ±11) °C.

(e) *Optional sample-conditioning components for PM sampling.* You may use the following sample-conditioning components to prepare PM samples for analysis, as long you do not install or use them in a way that adversely affects your ability to show that your engines comply with the applicable PM emission standards. You may condition PM samples to minimize positive and negative biases to PM results, as follows:

(1) *PM preclassifier.* You may use a PM preclassifier to remove large-diameter particles. The PM preclassifier may be either an inertial impactor or a cyclonic separator. It must be constructed of 300 series stainless steel. The preclassifier must be rated to remove at least 50% of PM at an

aerodynamic diameter of 10 µm and no more than 1% of PM at an aerodynamic diameter of 1 µm over the range of flow rates for which you use it. Follow the preclassifier manufacturer's instructions for any periodic servicing that may be necessary to prevent a buildup of PM. Install the preclassifier in the dilution system downstream of the last dilution stage. Configure the preclassifier outlet with a means of bypassing any PM sample media so the preclassifier flow may be stabilized before starting a test. Locate PM sample media within 50 cm downstream of the preclassifier's exit. You may not use this preclassifier if you use a PM probe that already has a preclassifier. For example, if you use a hat-shaped preclassifier that is located immediately upstream of the probe in such a way that it forces the sample flow to change direction before entering the probe, you may not use any other preclassifier in your PM sampling system.

(2) *Other components.* You may request to use other PM conditioning components upstream of a PM preclassifier, such as components that condition humidity or remove gaseous-phase hydrocarbons from the diluted exhaust stream. You may use such components only if we approve them under § 1065.10.

§ 1065.150 Continuous sampling.

You may use continuous sampling techniques for measurements that involve raw or dilute sampling. Make sure continuous sampling systems meet the specifications in § 1065.145. Make sure continuous analyzers meet the specifications in subparts C and D of this part.

§ 1065.170 Batch sampling for gaseous and PM constituents.

Batch sampling involves collecting and storing emissions for later analysis.

Examples of batch sampling include collecting and storing gaseous emissions in a bag and collecting and storing PM on a filter. You may use batch sampling to store emissions that have been diluted at least once in some way, such as with CVS, PFD, or BMD. You may use batch-sampling to store undiluted emissions only if we approve it as an alternate procedure under § 1065.10.

(a) *Sampling methods.* For batch sampling, extract the sample at a rate proportional to the exhaust flow. If you extract from a constant-volume flow rate, sample at a constant-volume flow rate. If you extract from a varying flow rate, vary the sample rate in proportion to the varying flow rate. Validate proportional sampling after an emission test as described in § 1065.545. Use storage media that do not change measured emission levels (either up or down). For example, do not use sample bags for storing emissions if the bags are permeable with respect to emissions or if they off-gas emissions. As another example, do not use PM filters that irreversibly absorb or adsorb gases.

(b) *Gaseous sample storage media.* Store gas volumes in sufficiently clean containers that minimally off-gas or allow permeation of gases. Use good engineering judgment to determine acceptable thresholds of storage media cleanliness and permeation. To clean a container, you may repeatedly purge and evacuate a container and you may heat it. Use a flexible container (such as a bag) within a temperature-controlled environment, or use a temperature controlled rigid container that is initially evacuated or has a volume that can be displaced, such as a piston and cylinder arrangement. Use containers meeting the specifications in the following table, noting that you may request to use other container materials under § 1065.10:

TABLE 1 OF § 1065.170.—GASEOUS BATCH SAMPLING CONTAINER MATERIALS

Emissions	Engines	
	Compression-ignition, two-stroke spark ignition, 4-stroke spark-ignition <19 kW	All other engines
CO, CO ₂ , O ₂ , CH ₄ , C ₂ H ₆ , C ₃ H ₈ , NO, NO ₂ ¹ .	Tedlar _{TM} , ² Kynar _{TM} , ² Teflon _{TM} , ³ or 300 series stainless steel ³	Tedlar _{TM} , ² Kynar _{TM} , ² Teflon _{TM} , ³ or 300 series stainless steel ³
THC, NMHC	Teflon _{TM} ⁴ or 300 series stainless steel ⁴	Tedlar _{TM} , ² Kynar _{TM} , ² Teflon _{TM} , ³ or 300 series stainless steel ³

¹ As long as you prevent aqueous condensation in storage container.
² Up to 40 °C.
³ Up to 202 °C.
⁴ At (191 ±11) °C.

(c) *PM sample media.* Apply the following methods for sampling particulate emissions:

(1) If you use filter-based sampling media to extract and store PM for

measurement, your procedure must meet the following specifications:
 (i) If you expect that a filter's total surface concentration of PM will exceed

0.473 mm/mm² for a given test interval, you may use filter media with a minimum initial collection efficiency of 98%; otherwise you must use a filter media with a minimum initial collection efficiency of 99.7%.

Collection efficiency must be measured as described in ASTM D 2986-95a (incorporated by reference in § 1065.1010), though you may rely on the sample-media manufacturer's measurements reflected in their product ratings to show that you meet applicable requirements.

(ii) The filter must be circular, with an overall diameter of 46.50 ± 0.6 mm and an exposed diameter of at least 38 mm. See the cassette specifications in paragraph (c)(1)(vi) of this section.

(iii) We highly recommend that you use a pure PTFE filter material that does not have any flow-through support bonded to the back and has an overall thickness of 40 ± 20 μ m. An inert polymer ring may be bonded to the periphery of the filter material for support and for sealing between the filter cassette parts. We consider Polymethylpentene (PMP) and PTFE inert materials for a support ring, but other inert materials may be used. See

the cassette specifications in paragraph (c)(1)(v) of this section. We allow the use of PTFE-coated glass fiber filter material, as long as this filter media selection does not affect your ability to demonstrate compliance with the applicable standards, which we base on a pure PTFE filter material. Note that we will use pure PTFE filter material for compliance testing, and we may require you to use pure PTFE filter material for any compliance testing we require, such as for selective enforcement audits.

(iv) You may request to use other filter materials or sizes under the provisions of § 1065.10.

(v) To minimize turbulent deposition and to deposit PM evenly on a filter, use a 12.5° (from center) divergent cone angle to transition from the transfer-line inside diameter to the exposed diameter of the filter face. Use 300 series stainless steel for this transition.

(vi) Maintain sample velocity at the filter face at or below 100 cm/s, where filter face velocity is the measured volumetric flow rate of the sample at the pressure and temperature upstream of the filter face, divided by the filter's exposed area.

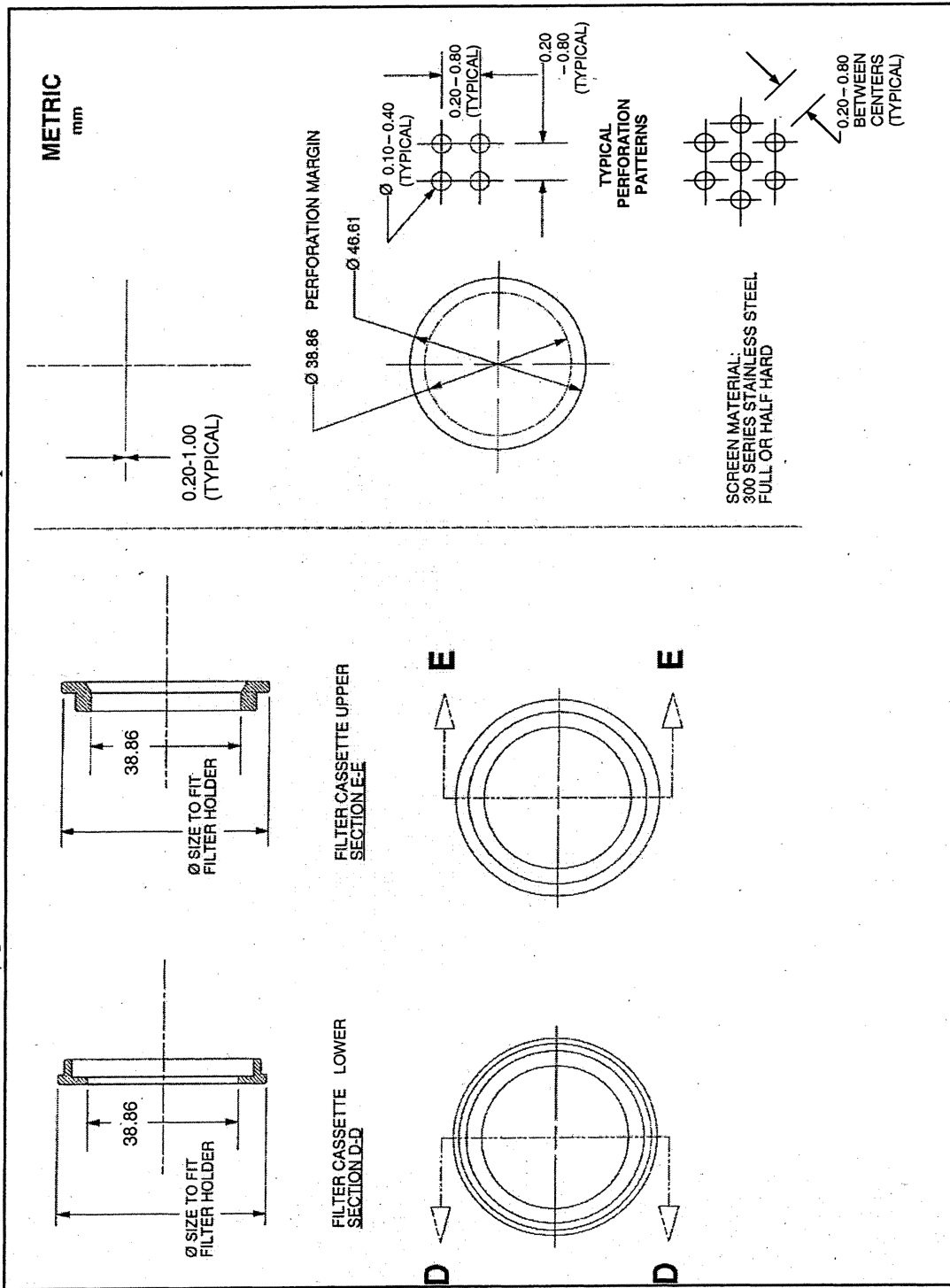
(vii) Use a clean cassette designed to the specifications of Figure 1 of § 1065.170 and made of any of the following materials: Delrin™, 300 series stainless steel, polycarbonate, acrylonitrile-butadiene-styrene (ABS) resin, or conductive polypropylene. We recommend that you keep filter cassettes clean by periodically washing or wiping them with a compatible solvent applied using a lint-free cloth. Depending upon your cassette material, ethanol (C₂H₅OH) might be an acceptable solvent. Your cleaning frequency will depend on your engine's PM and HC emissions.

(viii) If you store filters in cassettes in an automatic PM sampler, cover or seal individual filter cassettes after sampling to prevent communication of semi-volatile matter from one filter to another.

(2) You may use other PM sample media that we approve under § 1065.10, including non-filtering techniques. For example, you might deposit PM on an inert substrate that collects PM using electrostatic, thermophoresis, inertia, diffusion, or some other deposition mechanism, as approved.

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Figure 1 of §1065.170—PM filter cassette specifications.



BILLING CODE 6560-50-C

§ 1065.190 PM-stabilization and weighing environments for gravimetric analysis.

(a) This section describes the two environments required to stabilize and weigh PM for gravimetric analysis: the PM stabilization environment, where filters are stored before weighing; and the weighing environment, where the balance is located. The two environments may share a common

space. These volumes may be one or more rooms, or they may be much smaller, such as a glove box or an automated weighing system consisting of one or more countertop-sized environments.

(b) We recommend that you keep both the stabilization and the weighing environments free of ambient contaminants, such as dust, aerosols, or semi-volatile material that could

contaminate PM samples. We recommend that these environments conform with an "as-built" Class Six clean room specification according to ISO 14644-1 (incorporated by reference in § 1065.1010); however, we also recommend that you deviate from ISO 14644-1 as necessary to minimize air motion that might affect weighing. We recommend maximum air-supply and

air-return velocities of 0.05 m/s in the weighing environment.

(c) Verify the cleanliness of the PM-stabilization environment using reference filters, as described in § 1065.390(b).

(d) Maintain the following ambient conditions within the two environments during all stabilization and weighing:

(1) *Ambient temperature and tolerances.* Maintain the weighing environment at a tolerance of (22 ± 1) °C. If the two environments share a

common space, maintain both environments at a tolerance of (22 ± 1) °C. If they are separate, maintain the stabilization environment at a tolerance of (22 ± 3) °C.

(2) *Dewpoint.* Maintain a dewpoint of 9.5 °C in both environments. This dewpoint will control the amount of water associated with sulfuric acid (H₂SO₄) PM, such that 1.1368 grams of water will be associated with each gram of H₂SO₄.

(3) *Dewpoint tolerances.* If the expected fraction of sulfuric acid in PM is unknown, we recommend controlling dewpoint at within ± 1 °C tolerance. This would limit any dewpoint-related change in PM to less than $\pm 2\%$, even for PM that is 50% sulfuric acid. If you know your expected fraction of sulfuric acid in PM, we recommend that you select an appropriate dewpoint tolerance for showing compliance with emission standards using the following table as a guide:

TABLE 1 OF § 1065.190.—DEWPOINT TOLERANCE AS A FUNCTION OF % PM CHANGE AND % SULFURIC ACID PM

Expected sulfuric acid fraction of PM (percent)	$\pm 0.5\%$ PM mass change	$\pm 1.0\%$ PM mass change	$\pm 2.0\%$ PM mass change
5	± 3.0 °C	± 6.0 °C	± 12 °C
50	± 0.30 °C ..	± 0.60 °C ..	± 1.2 °C
100	± 0.15 °C ..	± 0.30 °C ..	± 0.60 °C

(e) Verify the following ambient conditions using measurement instruments that meet the specifications in subpart C of this part:

(1) Continuously measure dewpoint and ambient temperature. Use these values to determine if the stabilization and weighing environments have remained within the tolerances specified in paragraph (d) of this section for at least the past 60 min. We recommend that you provide an interlock that automatically prevents the balance from reporting values if either of the environments have not been within the applicable tolerances for the past 60 min.

(2) Continuously measure atmospheric pressure within the weighing environment. You may use a shared atmospheric pressure meter as long as you can show that your equipment for handling the weighing environment air maintains ambient pressure at the balance within ± 100 Pa of the shared atmospheric pressure. Provide a means to record the most recent atmospheric pressure when you weigh each PM sample. Use this value to calculate the PM buoyancy correction in § 1065.690.

(f) We recommend that you install a balance as follows:

(1) Install the balance on a vibration-isolation platform to isolate it from external noise and vibration.

(2) Shield the balance from convective airflow with a static-dissipating draft shield that is electrically grounded.

(3) Follow the balance manufacturer's specifications for all preventive maintenance.

(4) Operate the balance manually or as part of an automated weighing system.

(g) Minimize static electric charge in the balance environment, as follows:

(1) Electrically ground the balance.

(2) Use 300 series stainless steel tweezers if PM samples must be handled manually.

(3) Ground tweezers with a grounding strap, or provide a grounding strap for the operator such that the grounding strap shares a common ground with the balance. Make sure grounding straps have an appropriate resistor to protect operators from accidental shock.

(4) Provide a static-electricity neutralizer that is electrically grounded in common with the balance to remove static charge from PM samples, as follows:

(i) You may use radioactive neutralizers such as a Polonium (²¹⁰Po) source. Replace radioactive sources at the intervals recommended by the neutralizer manufacturer.

(ii) You may use other neutralizers, such as corona-discharge ionizers. If you use a corona-discharge ionizer, we recommend that you monitor it for neutral net charge according to the ionizer manufacturer's recommendations.

(5) We recommend that you use a device to monitor the static charge of PM sample media surfaces.

(6) We recommend that you neutralize PM sample media to within ± 2.0 V of neutral.

§ 1065.195 PM-stabilization environment for in-situ analyzers.

(a) This section describes the environment required to determine PM in-situ. For in-situ analyzers, such as an inertial balance, this is the environment within a PM sampling system that

surrounds the PM sample media. This is typically a very small volume.

(b) Maintain the environment free of ambient contaminants, such as dust, aerosols, or semi-volatile material that could contaminate PM samples. Filter all air used for stabilization with HEPA filters. Ensure that HEPA filters are installed properly so that background PM does not leak past the HEPA filters.

(c) Maintain the following thermodynamic conditions within the environment before measuring PM:

(1) *Ambient temperature.* Select a nominal ambient temperature, T_{amb} , between (42 and 52) °C. Maintain the ambient temperature within ± 1.0 °C of the selected nominal value.

(2) *Dewpoint.* Select a dewpoint, T_{dew} , that corresponds to T_{amb} such that $T_{dew} = (0.95T_{amb} - 11.40)$ °C. The resulting dewpoint will control the amount of water associated with sulfuric acid (H₂SO₄) PM, such that 1.1368 grams of water will be associated with each gram of H₂SO₄. For example, if you select a nominal ambient temperature of 47 °C, set a dewpoint of 33.3 °C.

(3) *Dewpoint tolerance.* If the expected fraction of sulfuric acid in PM is unknown, we recommend controlling dewpoint within ± 1.0 °C. This would limit any dewpoint-related change in PM to less than $\pm 2\%$, even for PM that is 50% sulfuric acid. If you know your expected fraction of sulfuric acid in PM, we recommend that you select an appropriate dewpoint tolerance for showing compliance with emission standards using Table 1 of § 1065.190 as a guide:

(4) *Absolute pressure.* Maintain an absolute pressure of (80.000 to 103.325) kPa. Use good engineering judgment to

maintain a more stringent tolerance of absolute pressure if your PM measurement instrument requires it.

(d) Continuously measure dewpoint, temperature, and pressure using measurement instruments that meet the PM-stabilization environment specifications in subpart C of this part. Use these values to determine if the in-situ stabilization environment is within the tolerances specified in paragraph (c) of this section. Do not use any PM quantities that are recorded when any of these parameters exceed the applicable tolerances.

(e) If you use an inertial PM balance, we recommend that you install it as follows:

(1) Isolate the balance from any external noise and vibration that is within a frequency range that could affect the balance.

(2) Follow the balance manufacturer's specifications.

(f) If static electricity affects an inertial balance, you may use a static neutralizer, as follows:

(1) You may use a radioactive neutralizer such as a Polonium (²¹⁰Po) source or a Krypton (⁸⁵Kr) source. Replace radioactive sources at the intervals recommended by the neutralizer manufacturer.

(2) You may use other neutralizers, such as a corona-discharge ionizer. If you use a corona-discharge ionizer, we recommend that you monitor it for neutral net charge according to the ionizer manufacturer's recommendations.

Subpart C—Measurement Instruments

§ 1065.201 Overview and general provisions.

(a) *Scope.* This subpart specifies measurement instruments and associated system requirements related to emission testing in a laboratory and

in the field. This includes laboratory instruments and portable emission measurement systems (PEMS) for measuring engine parameters, ambient conditions, flow-related parameters, and emission concentrations.

(b) *Instrument types.* You may use any of the specified instruments as described in this subpart to perform emission tests. If you want to use one of these instruments in a way that is not specified in this subpart, or if you want to use a different instrument, you must first get us to approve your alternate procedure under § 1065.10. Where we specify more than one instrument for a particular measurement, we may identify which instrument serves as the reference for showing that an alternative procedure is equivalent to the specified procedure.

(c) *Measurement systems.* Assemble a system of measurement instruments that allows you to show that your engines comply with the applicable emission standards, using good engineering judgment. When selecting instruments, consider how conditions such as vibration, temperature, pressure, humidity, viscosity, specific heat, and exhaust composition (including trace concentrations) may affect instrument compatibility and performance.

(d) *Redundant systems.* For all measurement instruments described in this subpart, you may use data from multiple instruments to calculate test results for a single test. If you use redundant systems, use good engineering judgment to use multiple measured values in calculations or to disregard individual measurements. Note that you must keep your results from all measurements, as described in § 1065.25. This requirements applies whether or not you actually use the measurements in your calculations.

(e) *Range.* You may use an instrument's response above 100% of its operating range if this does not affect your ability to show that your engines comply with the applicable emission standards. Note that we require additional testing and reporting if an analyzer responds above 100% of its range. See § 1065.550. Auto-ranging analyzers do not require additional testing or reporting.

(f) *Related subparts for laboratory testing.* Subpart D of this part describes how to evaluate the performance of the measurement instruments in this subpart. In general, if an instrument is specified in a specific section of this subpart, its calibration and verifications are typically specified in a similarly numbered section in subpart D of this part. For example, § 1065.290 gives instrument specifications for PM balances and § 1065.390 describes the corresponding calibrations and verifications. Note that some instruments also have other requirements in other sections of subpart D of this part. Subpart B of this part identifies specifications for other types of equipment, and subpart H of this part specifies engine fluids and analytical gases.

(g) *Field testing and testing with PEMS.* Subpart J of this part describes how to use these and other measurement instruments for field testing and other PEMS testing.

§ 1065.202 Data updating, recording, and control.

Your test system must be able to update data, record data and control systems related to operator demand, the dynamometer, sampling equipment, and measurement instruments. Use data acquisition and control systems that can record at the specified minimum frequencies, as follows:

TABLE OF § 1065.202.—DATA RECORDING AND CONTROL MINIMUM FREQUENCIES

Applicable test protocol section	Measured values	Minimum command and control frequency	Minimum recording frequency
§ 1065.510	Speed and torque during an engine step-map	1 Hz	1 mean value per step.
§ 1065.510	Speed and torque during an engine sweep-map	5 Hz	1 Hz means.
§ 1065.514, § 1065.530	Transient duty cycle reference and feedback speeds and torques.	5 Hz	1 Hz means.
§ 1065.514, § 1065.530	Steady-state and ramped-modal duty cycle reference and feedback speeds and torques.	1 Hz	1 Hz.
§ 1065.520, § 1065.530, § 1065.550	Continuous concentrations of raw or dilute analyzers ..	N/A	1 Hz.
§ 1065.520, § 1065.530, § 1065.550	Batch concentrations of raw or dilute analyzers	N/A	1 mean value per test interval.
§ 1065.530, § 1065.545	Diluted exhaust flow rate from a CVS with a heat exchanger upstream of the flow measurement.	N/A	1 Hz.
§ 1065.530, § 1065.545	Diluted exhaust flow rate from a CVS without a heat exchanger upstream of the flow measurement.	5 Hz	1 Hz means.

TABLE OF § 1065.202.—DATA RECORDING AND CONTROL MINIMUM FREQUENCIES—Continued

Applicable test protocol section	Measured values	Minimum command and control frequency	Minimum recording frequency
§ 1065.530, § 1065.545	Intake-air or raw-exhaust flow rate	N/A	1 Hz means.
§ 1065.530, § 1065.545	Dilution air if actively controlled	5 Hz	1 Hz means.
§ 1065.530	Sample flow from a CVS that has a heat exchanger ...	1 Hz	1 Hz.
§ 1065.530, § 1065.545	Sample flow from a CVS does not have a heat exchanger.	5 Hz	1 Hz mean.

§ 1065.205 Performance specifications for measurement instruments.

Your test system as a whole must meet all the applicable calibrations, verifications, and test-validation criteria specified in subparts D and F of this

part or subpart J of this part for using PEMS and for performing field testing. We recommend that your instruments meet the specifications in Table 1 of this section for all ranges you use for testing. We also recommend that you keep any

documentation you receive from instrument manufacturers showing that your instruments meet the specifications in Table 1 of this section.

Table 1 of §1065.205—Recommended performance specifications for measurement instruments

Measurement Instrument	Measured quantity symbol	Complete System Rise time and Fall time	Recording update frequency	Accuracy ^a	Repeatability ^a	Noise ^a
Engine speed transducer	f_n	1 s	1 Hz means	2.0 % of pt. or 0.5 % of max.	1.0 % of pt. or 0.25 % of max.	0.05 % of max.
Engine torque transducer	T	1 s	1 Hz means	2.0 % of pt. or 1.0 % of max.	1.0 % of pt. or 0.5 % of max.	0.05 % of max.
Electrical work (active-power meter)	W	1 s	1 Hz means	2.0 % of pt. or 0.5 % of max.	1.0 % of pt. or 0.25 % of max.	0.05 % of max.
General pressure transducer (not a part of another instrument)	p	5 s	1 Hz	2.0 % of pt. or 1.0 % of max.	1.0 % of pt. or 0.50 % of max.	0.1 % of max.
Atmospheric pressure meter used for PM-stabilization and balance environments	P_{atmos}	50 s	5 times per hour	50 Pa	25 Pa	5 Pa
General purpose atmospheric pressure meter	P_{atmos}	50 s	5 times per hour	250 Pa	100Pa	50 Pa
Temperature sensor for PM-stabilization and balance environments	T	50 s	0.1 Hz	0.25 K	0.1 K	0.1 K
Other temperature sensor (not a part of another instrument)	T	10 s	0.5 Hz	0.4 % of pt. K or 0.2 % of max. K	0.2 % of pt. K or 0.1 % of max. K	0.1 % of max.
Dewpoint sensor for PM-stabilization and balance environments	T_{dew}	50 s	0.1 Hz	0.25 K	0.1 K	0.02 K
Other dewpoint sensor	T_{dew}	50 s	0.1 Hz	1 K	0.5 K	0.1 K
Fuel flow meter (Fuel totalizer in parentheses)	\dot{m}	5 s (N/A)	1 Hz (N/A)	2.0 % of pt. or 1.5 % of max.	1.0 % of pt. or 0.75 % of max.	0.5 % of max.
Total diluted exhaust meter (CVS) (With heat exchanger before meter)	\dot{m}	1 s (5 s)	1 Hz means (1 Hz)	2.0 % of pt. or 1.5 % of max.	1.0 % of pt. or 0.75 % of max.	1.0 % of max.
Dilution air, inlet air, exhaust, and sample flow meters	\dot{m}	1 s	1 Hz means of 5 Hz samples	2.5 % of pt. or 1.5 % of max.	1.25 % of pt. or 0.75 % of max.	1.0 % of max.
Continuous gas analyzer	x	5 s	1 Hz	2.0 % of pt. or 2.0 % of meas.	1.0 % of pt. or 1.0 % of meas.	1.0 % of max.
Batch gas analyzer	x	N/A	N/A	2.0 % of pt. or 2.0 % of meas.	1.0 % of pt. or 1.0 % of meas.	1.0 % of max.
Gravimetric PM balance	m_{PM}	N/A	N/A	See §1065.790	0.5 µg	N/A
Inertial PM balance	m_{PM}	5 s	1 Hz	2.0 % of pt. or 2.0 % of meas.	1.0 % of pt. or 1.0 % of meas.	0.2 % of max.

^a Accuracy, repeatability, and noise are all determined with the same collected data, as described in §1065.305, and based on absolute values. "pt." refers to the overall flow-weighted mean value expected at the standard; "max." refers to the peak value expected at the standard over any test interval, not the maximum of the instrument's range; "meas" refers to the actual flow-weighted mean measured over any test interval.

Measurement of Engine Parameters and Ambient Conditions

§ 1065.210 Work input and output sensors.

(a) *Application.* Use instruments as specified in this section to measure work inputs and outputs during engine operation. We recommend that you use sensors, transducers, and meters that meet the specifications in Table 1 of § 1065.205. Note that your overall

systems for measuring work inputs and outputs must meet the linearity verifications in § 1065.307. We recommend that you measure work inputs and outputs where they cross the system boundary as shown in Figure 1 of this section. The system boundary is different for air-cooled engines than for liquid-cooled engines. If you choose to measure work before or after a work conversion, relative to the system

boundary, use good engineering judgment to estimate any work-conversion losses in a way that avoids overestimation of total work. For example, if it is impractical to instrument the shaft of an exhaust turbine generating electrical work, you may decide to measure its converted electrical work. In this case, divide the electrical work by an accurate value of electrical generator efficiency ($\eta < 1$), or

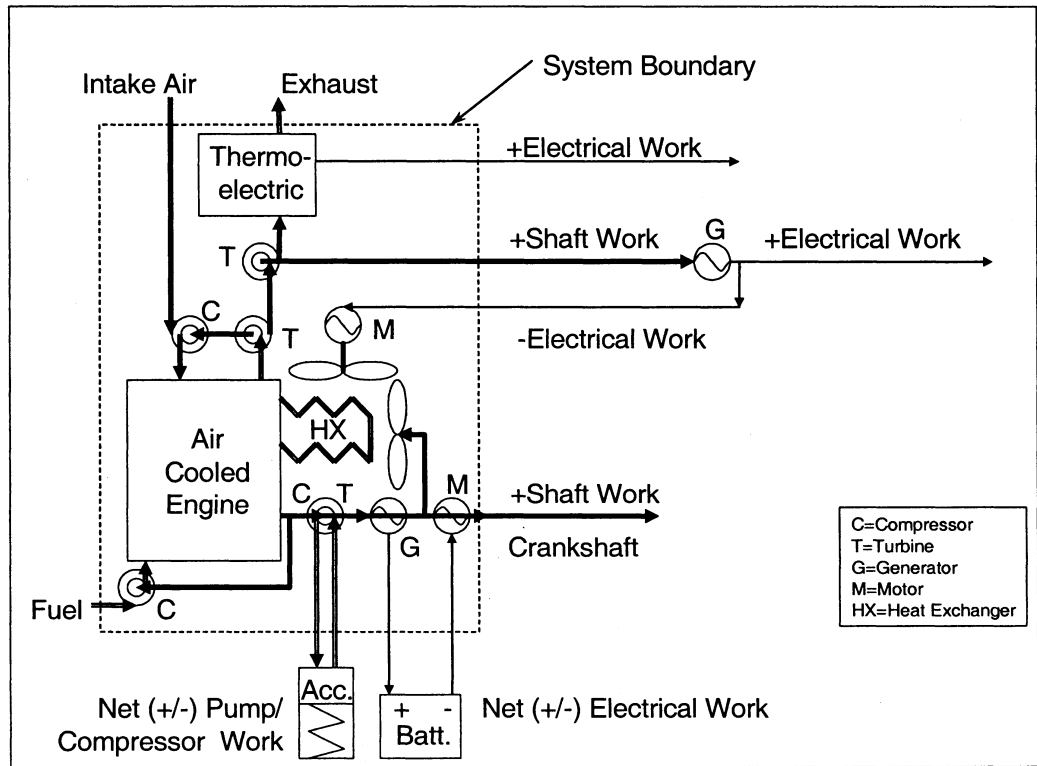
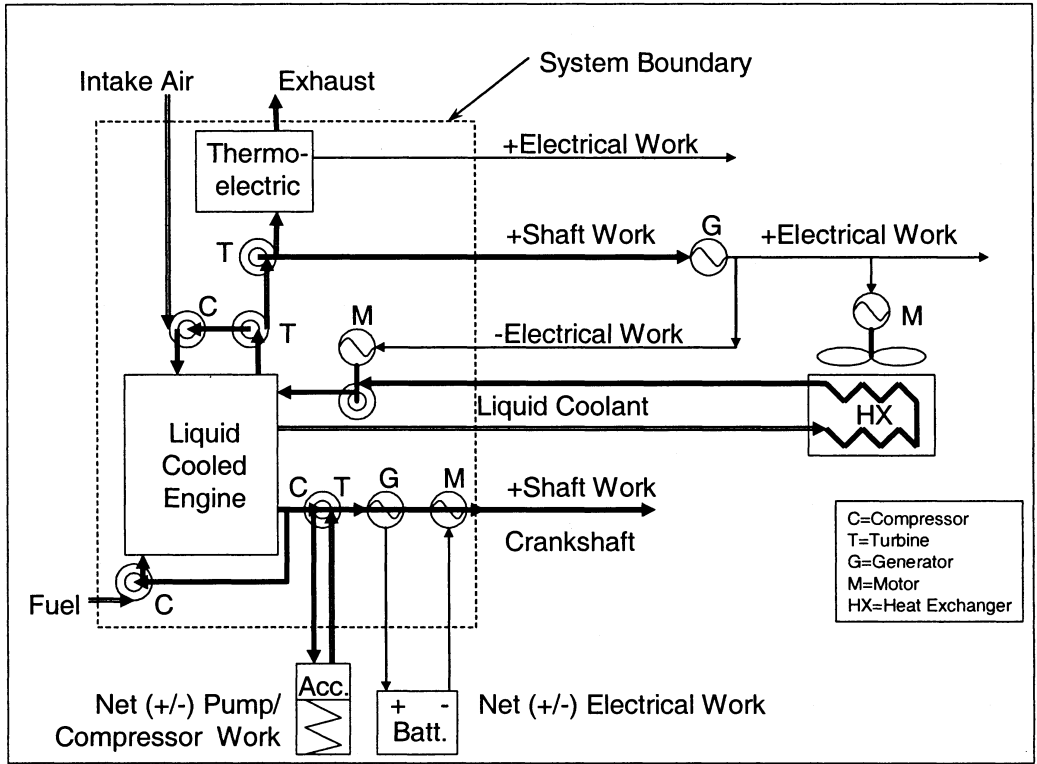
assume an efficiency of 1 ($\eta=1$), which would over-estimate brake-specific emissions. Do not underestimate the generator's efficiency because this

would result in an under-estimation of brake-specific emissions. In all cases, ensure that you are able to accurately

demonstrate compliance with the applicable standards.

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Figure 1 of §1065.210: Work inputs, outputs, and system boundaries for liquid-cooled and air-cooled engines.



(b) *Shaft work.* Use speed and torque transducer outputs to calculate total work according to § 1065.650.

(1) *Speed.* Use a magnetic or optical shaft-position detector with a resolution of at least 60 counts per revolution, in combination with a frequency counter that rejects common-mode noise.

(2) *Torque.* You may use a variety of methods to determine engine torque. As needed, and based on good engineering judgment, compensate for torque induced by the inertia of accelerating and decelerating components connected to the flywheel, such as the drive shaft and dynamometer rotor. Use any of the following methods to determine engine torque:

(i) Measure torque by mounting a strain gage or similar instrument in-line between the engine and dynamometer.

(ii) Measure torque by mounting a strain gage or similar instrument on a lever arm connected to the dynamometer housing.

(iii) Calculate torque from internal dynamometer signals, such as armature current, as long as you calibrate this measurement as described in § 1065.310.

(c) *Electrical work.* Use a watt-hour meter output to calculate total work according to § 1065.650. Use a watt-hour meter that outputs active power (kW). Watt-hour meters typically combine a Wheatstone bridge voltmeter and a Hall-effect clamp-on ammeter into a single microprocessor-based instrument that analyzes and outputs several parameters, such as alternating or direct current voltage (V), current (A), power factor (pf), apparent power (VA), reactive power (VAR), and active power (W).

(d) *Pump, compressor or turbine work.* Use pressure transducer and flow-meter outputs to calculate total work according to § 1065.650. For flow meters, see § 1065.220 through § 1065.248.

§ 1065.215 Pressure transducers, temperature sensors, and dewpoint sensors.

(a) *Application.* Use instruments as specified in this section to measure pressure, temperature, and dewpoint.

(b) *Component requirements.* We recommend that you use pressure transducers, temperature sensors, and dewpoint sensors that meet the specifications in Table 1 of § 1065.205. Note that your overall systems for measuring pressure, temperature, and dewpoint must meet the calibration and verifications in § 1065.315.

(c) *Temperature.* For PM-balance environments or other precision temperature measurements over a

narrow temperature range, we recommend thermistors. For other applications we recommend thermocouples that are not grounded to the thermocouple sheath. You may use other temperature sensors, such as resistive temperature detectors (RTDs).

(d) *Pressure.* Pressure transducers must be located in a temperature-controlled environment, or they must compensate for temperature changes over their expected operating range. Transducer materials must be compatible with the fluid being measured. For atmospheric pressure or other precision pressure measurements, we recommend either capacitance-type, quartz crystal, or laser-interferometer transducers. For other applications, we recommend either strain gage or capacitance-type pressure transducers. You may use other pressure-measurement instruments, such as manometers, where appropriate.

(e) *Dewpoint.* For PM-stabilization environments, we recommend chilled-surface hygrometers. For other applications, we recommend thin-film capacitance sensors. You may use other dewpoint sensors, such as a wet-bulb/dry-bulb psychrometer, where appropriate.

Flow-Related Measurements

§ 1065.220 Fuel flow meter.

(a) *Application.* You may use fuel flow in combination with a chemical balance of carbon (or oxygen) between the fuel, inlet air, and raw exhaust to calculate raw exhaust flow as described in § 1065.650, as follows:

(1) Use the actual value of calculated raw exhaust flow rate in the following cases:

(i) For multiplying raw exhaust flow rate with continuously sampled concentrations.

(ii) For multiplying total raw exhaust flow with batch-sampled concentrations.

(2) In the following cases, you may use a fuel flow meter signal that does not give the actual value of raw exhaust, as long as it is linearly proportional to the exhaust molar flow rate's actual calculated value:

(i) For feedback control of a proportional sampling system, such as a partial-flow dilution system.

(ii) For multiplying with continuously sampled gas concentrations, if the same signal is used in a chemical-balance calculation to determine work from brake-specific fuel consumption and fuel consumed.

(b) *Component requirements.* We recommend that you use a fuel flow meter that meets the specifications in

Table 1 of § 1065.205. We recommend a fuel flow meter that measures mass directly, such as one that relies on gravimetric or inertial measurement principles. This may involve using a meter with one or more scales for weighing fuel or using a Coriolis meter. Note that your overall system for measuring fuel flow must meet the linearity verification in § 1065.307 and the calibration and verifications in § 1065.320.

(c) *Recirculating fuel.* In any fuel-flow measurement, account for any fuel that bypasses the engine or returns from the engine to the fuel storage tank.

(d) *Flow conditioning.* For any type of fuel flow meter, condition the flow as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. You may accomplish this by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, straightening fins, or pneumatic pulsation dampeners to establish a steady and predictable velocity profile upstream of the meter.

§ 1065.225 Intake-air flow meter.

(a) *Application.* You may use an intake-air flow meter in combination with a chemical balance of carbon (or oxygen) between the fuel, inlet air, and raw exhaust to calculate raw exhaust flow as described in § 1065.650, as follows:

(1) Use the actual value of calculated raw exhaust in the following cases:

(i) For multiplying raw exhaust flow rate with continuously sampled concentrations.

(ii) For multiplying total raw exhaust flow with batch-sampled concentrations.

(2) In the following cases, you may use an intake-air flow meter signal that does not give the actual value of raw exhaust, as long as it is linearly proportional to the exhaust flow rate's actual calculated value:

(i) For feedback control of a proportional sampling system, such as a partial-flow dilution system.

(ii) For multiplying with continuously sampled gas concentrations, if the same signal is used in a chemical-balance calculation to determine work from brake-specific fuel consumption and fuel consumed.

(b) *Component requirements.* We recommend that you use an intake-air flow meter that meets the specifications in Table 1 of § 1065.205. This may include a laminar flow element, an ultrasonic flow meter, a subsonic venturi, a thermal-mass meter, an

averaging Pitot tube, or a hot-wire anemometer. Note that your overall system for measuring intake-air flow must meet the linearity verification in § 1065.307 and the calibration in § 1065.325.

(c) *Flow conditioning.* For any type of intake-air flow meter, condition the flow as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. You may accomplish this by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, orifice plates or straightening fins to establish a predictable velocity profile upstream of the meter.

§ 1065.230 Raw exhaust flow meter.

(a) *Application.* You may use measured raw exhaust flow, as follows:

(1) Use the actual value of calculated raw exhaust in the following cases:

(i) Multiply raw exhaust flow rate with continuously sampled concentrations.

(ii) Multiply total raw exhaust with batch sampled concentrations.

(2) In the following cases, you may use a raw exhaust flow meter signal that does not give the actual value of raw exhaust, as long as it is linearly proportional to the exhaust flow rate's actual calculated value:

(i) For feedback control of a proportional sampling system, such as a partial-flow dilution system.

(ii) For multiplying with continuously sampled gas concentrations, if the same signal is used in a chemical-balance calculation to determine work from brake-specific fuel consumption and fuel consumed.

(b) *Component requirements.* We recommend that you use a raw-exhaust flow meter that meets the specifications in Table 1 of § 1065.205. This may involve using an ultrasonic flow meter, a subsonic venturi, an averaging Pitot tube, a hot-wire anemometer, or other measurement principle. This would generally not involve a laminar flow element or a thermal-mass meter. Note that your overall system for measuring raw exhaust flow must meet the linearity verification in § 1065.307 and the calibration and verifications in § 1065.330. Any raw-exhaust meter must be designed to appropriately compensate for changes in the raw exhaust's thermodynamic, fluid, and compositional states.

(c) *Flow conditioning.* For any type of raw exhaust flow meter, condition the flow as needed to prevent wakes, eddies, circulating flows, or flow

pulsations from affecting the accuracy or repeatability of the meter. You may accomplish this by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, orifice plates or straightening fins to establish a predictable velocity profile upstream of the meter.

(d) *Exhaust cooling.* You may cool raw exhaust upstream of a raw-exhaust flow meter, as long as you observe all the following provisions:

(1) Do not sample PM downstream of the cooling.

(2) If cooling causes exhaust temperatures above 202 °C to decrease to below 180 °C, do not sample NMHC downstream of the cooling for compression-ignition engines, 2-stroke spark-ignition engines, and 4-stroke spark ignition engines below 19 kW.

(3) If cooling causes aqueous condensation, do not sample NO_x downstream of the cooling unless the cooler meets the performance verification in § 1065.376.

(4) If cooling causes aqueous condensation before the flow reaches a flow meter, measure dewpoint, T_{dew} and pressure, p_{total} at the flow meter inlet. Use these values in emission calculations according to § 1065.650.

§ 1065.240 Dilution air and diluted exhaust flow meters.

(a) *Application.* Use a diluted exhaust flow meter to determine instantaneous diluted exhaust flow rates or total diluted exhaust flow over a test interval. You may use the difference between a diluted exhaust flow meter and a dilution air meter to calculate raw exhaust flow rates or total raw exhaust flow over a test interval.

(b) *Component requirements.* We recommend that you use a diluted exhaust flow meter that meets the specifications in Table 1 of § 1065.205. Note that your overall system for measuring diluted exhaust flow must meet the linearity verification in § 1065.307 and the calibration and verifications in § 1065.340 and § 1065.341. You may use the following meters:

(1) For constant-volume sampling (CVS) of the total flow of diluted exhaust, you may use a critical-flow venturi (CFV) or multiple critical-flow venturis arranged in parallel, a positive-displacement pump (PDP), a subsonic venturi (SSV), or an ultrasonic flow meter (UFM). Combined with an upstream heat exchanger, either a CFV or a PDP will also function as a passive flow controller in a CVS system. However, you may also combine any

flow meter with any active flow control system to maintain proportional sampling of exhaust constituents. You may control the total flow of diluted exhaust, or one or more sample flows, or a combination of these flow controls to maintain proportional sampling.

(2) For any other dilution system, you may use a laminar flow element, an ultrasonic flow meter, a subsonic venturi, a critical-flow venturi or multiple critical-flow venturis arranged in parallel, a positive-displacement meter, a thermal-mass meter, an averaging Pitot tube, or a hot-wire anemometer.

(c) *Flow conditioning.* For any type of diluted exhaust flow meter, condition the flow as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. For some meters, you may accomplish this by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, orifice plates or straightening fins to establish a predictable velocity profile upstream of the meter.

(d) *Exhaust cooling.* You may cool diluted exhaust upstream of a raw-exhaust flow meter, as long as you observe all the following provisions:

(1) Do not sample PM downstream of the cooling.

(2) If cooling causes exhaust temperatures above 202 °C to decrease to below 180 °C, do not sample NMHC downstream of the cooling for compression-ignition engines, 2-stroke spark-ignition engines, and 4-stroke spark ignition engines below 19 kW.

(3) If cooling causes aqueous condensation, do not sample NO_x downstream of the cooling unless the cooler meets the performance verification in § 1065.376.

(4) If cooling causes aqueous condensation before the flow reaches a flow meter, measure dewpoint, T_{dew} and pressure, p_{total} at the flow meter inlet. Use these values in emission calculations according to § 1065.650.

§ 1065.245 Sample flow meter for batch sampling.

(a) *Application.* Use a sample flow meter to determine sample flow rates or total flow sampled into a batch sampling system over a test interval. You may use the difference between a diluted exhaust sample flow meter and a dilution air meter to calculate raw exhaust flow rates or total raw exhaust flow over a test interval.

(b) *Component requirements.* We recommend that you use a sample flow meter that meets the specifications in

Table 1 of § 1065.205. This may involve a laminar flow element, an ultrasonic flow meter, a subsonic venturi, a critical-flow venturi or multiple critical-flow venturis arranged in parallel, a positive-displacement meter, a thermal-mass meter, an averaging Pitot tube, or a hot-wire anemometer. Note that your overall system for measuring sample flow must meet the linearity verification in § 1065.307. For the special case where CFVs are used for both the diluted exhaust and sample-flow measurements and their upstream pressures and temperatures remain similar during testing, you do not have to quantify the flow rate of the sample-flow CFV. In this special case, the sample-flow CFV inherently flow-weights the batch sample relative to the diluted exhaust CFV.

(c) *Flow conditioning.* For any type of sample flow meter, condition the flow as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. For some meters, you may accomplish this by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, orifice plates or straightening fins to establish a predictable velocity profile upstream of the meter.

§ 1065.248 Gas divider.

(a) *Application.* You may use a gas divider to blend calibration gases.

(b) *Component requirements.* Use a gas divider that blends gases to the specifications of § 1065.750 and to the flow-weighted concentrations expected during testing. You may use critical-flow gas dividers, capillary-tube gas dividers, or thermal-mass-meter gas dividers. Note that your overall gas-divider system must meet the linearity verification in § 1065.307.

CO and CO₂ Measurements

§ 1065.250 Nondispersive infra-red analyzer.

(a) *Application.* Use a nondispersive infra-red (NDIR) analyzer to measure CO and CO₂ concentrations in raw or diluted exhaust for either batch or continuous sampling.

(b) *Component requirements.* We recommend that you use an NDIR analyzer that meets the specifications in Table 1 of § 1065.205. Note that your NDIR-based system must meet the calibration and verifications in § 1065.350 and § 1065.355 and it must also meet the linearity verification in § 1065.307. You may use an NDIR analyzer that has compensation algorithms that are functions of other

gaseous measurements and the engine's known or assumed fuel properties. The target value for any compensation algorithm is 0.0% (that is, no bias high and no bias low), regardless of the uncompensated signal's bias.

Hydrocarbon Measurements

§ 1065.260 Flame-ionization detector.

(a) *Application.* Use a flame-ionization detector (FID) analyzer to measure hydrocarbon concentrations in raw or diluted exhaust for either batch or continuous sampling. Determine hydrocarbon concentrations on a carbon number basis of one, C₁. Determine methane and nonmethane hydrocarbon values as described in paragraph (e) of this section. See subpart I of this part for special provisions that apply to measuring hydrocarbons when testing with oxygenated fuels.

(b) *Component requirements.* We recommend that you use a FID analyzer that meets the specifications in Table 1 of § 1065.205. Note that your FID-based system for measuring THC, THCE, or CH₄ must meet all of the verifications for hydrocarbon measurement in subpart D of this part, and it must also meet the linearity verification in § 1065.307. You may use a FID that has compensation algorithms that are functions of other gaseous measurements and the engine's known or assumed fuel properties. The target value for any compensation algorithm is 0.0% (that is, no bias high and no bias low), regardless of the uncompensated signal's bias.

(c) *Heated FID analyzers.* For diesel-fueled engines, two-stroke spark-ignition engines, and four-stroke spark-ignition engines below 19 kW, you must use heated FID analyzers that maintain all surfaces that are exposed to emissions at a temperature of (191 ± 11) °C.

(d) *FID fuel and burner air.* Use FID fuel and burner air that meet the specifications of § 1065.750. Do not allow the FID fuel and burner air to mix before entering the FID analyzer to ensure that the FID analyzer operates with a diffusion flame and not a premixed flame.

(e) *Methane.* FID analyzers measure total hydrocarbons (THC). To determine nonmethane hydrocarbons (NMHC), quantify methane, CH₄, either with a nonmethane cutter and a FID analyzer as described in § 1065.265, or with a gas chromatograph as described in § 1065.267. Instead of measuring methane, you may assume that 2% of measured total hydrocarbons is methane, as described in § 1065.660. For a FID analyzer used to determine

NMHC, determine its response factor to CH₄, RF_{CH_4} , as described in § 1065.360. Note that NMHC-related calculations are described in § 1065.660.

§ 1065.265 Nonmethane cutter.

(a) *Application.* You may use a nonmethane cutter to measure CH₄ with a FID analyzer. A nonmethane cutter oxidizes all nonmethane hydrocarbons to CO₂ and H₂O. You may use a nonmethane cutter for raw or diluted exhaust for batch or continuous sampling.

(b) *System performance.* Determine nonmethane-cutter performance as described in § 1065.365 and use the results to calculate NMHC emission in § 1065.660.

(c) *Configuration.* Configure the nonmethane cutter with a bypass line for the verification described in § 1065.365.

(d) *Optimization.* You may optimize a nonmethane cutter to maximize the penetration of CH₄ and the oxidation of all other hydrocarbons. You may humidify a sample and you may dilute a sample with purified air or oxygen (O₂) upstream of the nonmethane cutter to optimize its performance. You must account for any sample humidification and dilution in emission calculations.

§ 1065.267 Gas chromatograph.

(a) *Application.* You may use a gas chromatograph to measure CH₄ concentrations of diluted exhaust for batch sampling. While you may also use a nonmethane cutter to measure CH₄, as described in § 1065.265, use a reference procedure based on a gas chromatograph for comparison with any proposed alternate measurement procedure under § 1065.10.

(b) *Component requirements.* We recommend that you use a gas chromatograph that meets the specifications in Table 1 of § 1065.205, and it must also meet the linearity verification in § 1065.307.

NO_x Measurements

§ 1065.270 Chemiluminescent detector.

(a) *Application.* You may use a chemiluminescent detector (CLD) to measure NO_x concentration in raw or diluted exhaust for batch or continuous sampling. We generally accept a CLD for NO_x measurement, even though it measures only NO and NO₂, when coupled with an NO₂-to-NO converter, since conventional engines and aftertreatment systems do not emit significant amounts of NO_x species other than NO and NO₂. Measure other NO_x species if required by the standard-setting part. While you may also use other instruments to measure NO_x, as

described in § 1065.272, use a reference procedure based on a chemiluminescent detector for comparison with any proposed alternate measurement procedure under § 1065.10.

(b) *Component requirements.* We recommend that you use a CLD that meets the specifications in Table 1 of § 1065.205. Note that your CLD-based system must meet the quench verification in § 1065.370 and it must also meet the linearity verification in § 1065.307. You may use a heated or unheated CLD, and you may use a CLD that operates at atmospheric pressure or under a vacuum. You may use a CLD that has compensation algorithms that are functions of other gaseous measurements and the engine's known or assumed fuel properties. The target value for any compensation algorithm is 0.0% (that is, no bias high and no bias low), regardless of the uncompensated signal's bias.

(c) *NO₂-to-NO converter.* Place upstream of the CLD an internal or external NO₂-to-NO converter that meets the verification in § 1065.378. Configure the converter with a bypass to facilitate this verification.

(d) *Humidity effects.* You must maintain all CLD temperatures to prevent aqueous condensation. To remove humidity from a sample upstream of a CLD, use one of the following configurations:

(1) Connect a CLD downstream of any dryer or chiller that is downstream of an NO₂-to-NO converter that meets the verification in § 1065.378.

(2) Connect a CLD downstream of any dryer or thermal chiller that meets the verification in § 1065.376.

(e) *Response time.* You may use a heated CLD to improve CLD response time.

§ 1065.272 Nondispersive ultraviolet analyzer.

(a) *Application.* You may use a nondispersive ultraviolet (NDUV) analyzer to measure NO_x concentration in raw or diluted exhaust for batch or continuous sampling. We generally accept an NDUV for NO_x measurement, even though it measures only NO and NO₂, since conventional engines and aftertreatment systems do not emit significant amounts of other NO_x species. Measure other NO_x species if required by the standard-setting part.

(b) *Component requirements.* We recommend that you use an NDUV analyzer that meets the specifications in Table 1 of § 1065.205. Note that your NDUV-based system must meet the verifications in § 1065.372 and it must also meet the linearity verification in § 1065.307. You may use a NDUV

analyzer that has compensation algorithms that are functions of other gaseous measurements and the engine's known or assumed fuel properties. The target value for any compensation algorithm is 0.0% (that is, no bias high and no bias low), regardless of the uncompensated signal's bias.

(c) *NO₂-to-NO converter.* If your NDUV analyzer measures only NO, place upstream of the NDUV analyzer an internal or external NO₂-to-NO converter that meets the verification in § 1065.378. Configure the converter with a bypass to facilitate this verification.

(d) *Humidity effects.* You must maintain NDUV temperature to prevent aqueous condensation, unless you use one of the following configurations:

(1) Connect an NDUV downstream of any dryer or chiller that is downstream of an NO₂-to-NO converter that meets the verification in § 1065.378.

(2) Connect an NDUV downstream of any dryer or thermal chiller that meets the verification in § 1065.376.

O₂ Measurements

§ 1065.280 Paramagnetic and magnetopneumatic O₂ detection analyzers.

(a) *Application.* You may use a paramagnetic detection (PMD) or magnetopneumatic detection (MPD) analyzer to measure O₂ concentration in raw or diluted exhaust for batch or continuous sampling. You may use O₂ measurements with intake air or fuel flow measurements to calculate exhaust flow rate according to § 1065.650.

(b) *Component requirements.* We recommend that you use a PMD/MPD analyzer that meets the specifications in Table 1 of § 1065.205. Note that it must meet the linearity verification in § 1065.307. You may use a PMD/MPD that has compensation algorithms that are functions of other gaseous measurements and the engine's known or assumed fuel properties. The target value for any compensation algorithm is 0.0% (that is, no bias high and no bias low), regardless of the uncompensated signal's bias.

Air-to-Fuel Ratio Measurements

§ 1065.284 Zirconia (ZrO₂) analyzer.

(a) *Application.* You may use a zirconia (ZrO₂) analyzer to measure air-to-fuel ratio in raw exhaust for continuous sampling. You may use O₂ measurements with intake air or fuel flow measurements to calculate exhaust flow rate according to § 1065.650.

(b) *Component requirements.* We recommend that you use a ZrO₂ analyzer that meets the specifications in Table 1 of § 1065.205. Note that your ZrO₂-based system must meet the

linearity verification in § 1065.307. You may use a Zirconia analyzer that has compensation algorithms that are functions of other gaseous measurements and the engine's known or assumed fuel properties. The target value for any compensation algorithm is 0.0% (that is, no bias high and no bias low), regardless of the uncompensated signal's bias.

PM Measurements

§ 1065.290 PM gravimetric balance.

(a) *Application.* Use a balance to weigh net PM on a sample medium for laboratory testing.

(b) *Component requirements.* We recommend that you use a balance that meets the specifications in Table 1 of § 1065.205. Note that your balance-based system must meet the linearity verification in § 1065.307. If the balance uses internal calibration weights for routine spanning and linearity verifications, the calibration weights must meet the specifications in § 1065.790. While you may also use an inertial balance to measure PM, as described in § 1065.295, use a reference procedure based on a gravimetric balance for comparison with any proposed alternate measurement procedure under § 1065.10.

(c) *Pan design.* We recommend that you use a balance pan designed to minimize corner loading of the balance, as follows:

(1) Use a pan that centers the PM sample on the weighing pan. For example, use a pan in the shape of a cross that has upswept tips that center the PM sample media on the pan.

(2) Use a pan that positions the PM sample as low as possible.

(d) *Balance configuration.* Configure the balance for optimum settling time and stability at your location.

§ 1065.295 PM inertial balance for field-testing analysis.

(a) *Application.* You may use an inertial balance to quantify net PM on a sample medium for field testing.

(b) *Component requirements.* We recommend that you use a balance that meets the specifications in Table 1 of § 1065.205. Note that your balance-based system must meet the linearity verification in § 1065.307. If the balance uses an internal calibration process for routine spanning and linearity verifications, the process must be NIST-traceable. You may use an inertial PM balance that has compensation algorithms that are functions of other gaseous measurements and the engine's known or assumed fuel properties. The target value for any compensation algorithm is 0.0% (that is, no bias high

and no bias low), regardless of the uncompensated signal's bias.

Subpart D—Calibrations and Verifications

§ 1065.301 Overview and general provisions.

(a) This subpart describes required and recommended calibrations and verifications of measurement systems. See subpart C of this part for specifications that apply to individual instruments.

(b) You must generally use complete measurement systems when performing calibrations or verifications in this

subpart. For example, this would generally involve evaluating instruments based on values recorded with the complete system you use for recording test data, including analog-to-digital converters. For some calibrations and verifications, we may specify that you disconnect part of the measurement system to introduce a simulated signal.

(c) If we do not specify a calibration or verification for a portion of a measurement system, calibrate that portion of your system and verify its performance at a frequency consistent with any recommendations from the measurement-system manufacturer,

consistent with good engineering judgment.

(d) Use NIST-traceable standards to the tolerances we specify for calibrations and verifications. Where we specify the need to use NIST-traceable standards, you may alternatively ask for our approval to use international standards that are not NIST-traceable.

§ 1065.303 Summary of required calibration and verifications.

The following table summarizes the required and recommended calibrations and verifications described in this subpart and indicates when these have to be performed:

TABLE 1 OF § 1065.303.—SUMMARY OF REQUIRED CALIBRATION AND VERIFICATIONS

Type of calibration or verification	Minimum frequency ^a
§ 1065.305: accuracy, repeatability and noise ...	<i>Accuracy:</i> Not required, but recommended for initial installation. <i>Repeatability:</i> Not required, but recommended for initial installation. <i>Noise:</i> Not required, but recommended for initial installation.
§ 1065.307: linearity	<i>Speed:</i> Upon initial installation, within 370 days before testing and after major maintenance. <i>Torque:</i> Upon initial installation, within 370 days before testing and after major maintenance. <i>Electrical power:</i> Upon initial installation, within 370 days before testing and after major maintenance. <i>Clean gas and diluted exhaust flows:</i> Upon initial installation, within 370 days before testing and after major maintenance, unless flow is verified by propane check or by carbon or oxygen balance. <i>Raw exhaust flow:</i> Upon initial installation, within 185 days before testing and after major maintenance, unless flow is verified by propane check or by carbon or oxygen balance. <i>Gas analyzers:</i> Upon initial installation, within 35 days before testing and after major maintenance. <i>PM balance:</i> Upon initial installation, within 370 days before testing and after major maintenance. <i>Stand-alone pressure and temperature:</i> Upon initial installation, within 370 days before testing and after major maintenance.
§ 1065.308: Continuous analyzer system response and recording.	Upon initial installation, after system reconfiguration, and after major maintenance.
§ 1065.309: Continuous analyzer uniform response.	Upon initial installation, after system reconfiguration, and after major maintenance.
§ 1065.310: torque	Upon initial installation and after major maintenance.
§ 1065.315: pressure, temperature, dewpoint	Upon initial installation and after major maintenance.
§ 1065.320: fuel flow	Upon initial installation and after major maintenance.
§ 1065.325: intake flow	Upon initial installation and after major maintenance.
§ 1065.330: exhaust flow	Upon initial installation and after major maintenance.
§ 1065.340: diluted exhaust flow (CVS)	Upon initial installation and after major maintenance.
§ 1065.341: CVS and batch sampler verification	Upon initial installation, within 35 days before testing, and after major maintenance.
§ 1065.345: vacuum leak	Before each laboratory test according to subpart F of this part and before each field test according to subpart J of this part.
§ 1065.350: CO ₂ NDIRH ₂ O interference	Upon initial installation and after major maintenance.
§ 1065.355: CO NDIRCO ₂ and H ₂ O interference	Upon initial installation and after major maintenance.
§ 1065.360: FID optimization, etc.	<i>Calibrate, optimize, and determine CH₄ response:</i> upon initial installation and after major maintenance. <i>Verify CH₄ response:</i> upon initial installation, within 185 days before testing, and after major maintenance.
§ 1065.362: raw exhaustFID O ₂ interference	Upon initial installation, after FID optimization according to § 1065.360, and after major maintenance.
§ 1065.365: nonmethane cutter penetration	Upon initial installation, within 185 days before testing, and after major maintenance.
§ 1065.370: CLD CO ₂ and H ₂ O quench	Upon initial installation and after major maintenance.
§ 1065.372: NDUV HC and H ₂ O interference	Upon initial installation and after major maintenance.
§ 1065.376: chiller NO ₂ penetration	Upon initial installation and after major maintenance.
§ 1065.378: NO ₂ -to-NO converter conversion	Upon initial installation, within 35 days before testing, and after major maintenance.
§ 1065.390: PM balance and weighing	<i>Independent verification:</i> upon initial installation, within 370 days before testing, and after major maintenance. <i>Zero, span, and reference sample verifications:</i> within 12 hours of weighing, and after major maintenance.
§ 1065.395: Inertial PM balance and weighing ..	Independent verification: upon initial installation, within 370 days before testing, and after major maintenance.

TABLE 1 OF § 1065.303.—SUMMARY OF REQUIRED CALIBRATION AND VERIFICATIONS—Continued

Type of calibration or verification	Minimum frequency ^a
	<i>Other verifications:</i> upon initial installation and after major maintenance.

^a Perform calibrations and verifications more frequently, according to measurement system manufacturer instructions and good engineering judgment.

§ 1065.305 Verifications for accuracy, repeatability, and noise.

(a) This section describes how to determine the accuracy, repeatability, and noise of an instrument. Table 1 of § 1065.205 specifies recommended values for individual instruments.

(b) We do not require you to verify instrument accuracy, repeatability, or noise.

However, it may be useful to consider these verifications to define a specification for a new instrument, to verify the performance of a new instrument upon delivery, or to troubleshoot an existing instrument.

(c) In this section we use the letter “y” to denote a generic measured quantity, the superscript over-bar to denote an arithmetic mean (such as \bar{y}), and the subscript “ref” to denote the reference quantity being measured.

(d) Conduct these verifications as follows:

(1) Prepare an instrument so it operates at its specified temperatures, pressures, and flows. Perform any instrument linearization or calibration procedures prescribed by the instrument manufacturer.

(2) Zero the instrument as you would before an emission test by introducing a zero signal. Depending on the instrument, this may be a zero-concentration gas, a reference signal, a set of reference thermodynamic conditions, or some combination of these. For gas analyzers, use a zero gas that meets the specifications of § 1065.750.

(3) Span the instrument as you would before an emission test by introducing a span signal. Depending on the instrument, this may be a span-concentration gas, a reference signal, a set of reference thermodynamic conditions, or some combination of these. For gas analyzers, use a span gas that meets the specifications of § 1065.750.

(4) Use the instrument to quantify a NIST-traceable reference quantity, y_{ref} . For gas analyzers the reference gas must meet the specifications of § 1065.750. Select a reference quantity near the mean value expected during testing. For all gas analyzers, use a quantity near the flow-weighted mean concentration expected at the standard or expected during testing, whichever is greater. For

a noise verification, use the same zero gas from paragraph (e) of this section as the reference quantity. In all cases, allow time for the instrument to stabilize while it measures the reference quantity. Stabilization time may include time to purge an instrument and time to account for its response.

(5) Sample and record values for 30 seconds, record the arithmetic mean, \bar{y}_i , and record the standard deviation, σ_i , of the recorded values. Refer to § 1065.602 for an example of calculating arithmetic mean and standard deviation.

(6) Also, if the reference quantity is not absolutely constant, which might be the case with a reference flow, sample and record values of y_{ref} for 30 seconds and record the arithmetic mean of the values, \bar{y}_{ref} . Refer to § 1065.602 for an example of calculating arithmetic mean.

(7) Subtract the reference value, y_{ref} (or \bar{y}_{ref}), from the arithmetic mean, \bar{y}_i . Record this value as the error, ϵ_i .

(8) Repeat the steps specified in paragraphs (d)(2) through (6) of this section until you have ten arithmetic means ($\bar{y}_1, \bar{y}_2, \bar{y}_i, \dots, \bar{y}_{10}$), ten standard deviations, ($\sigma_1, \sigma_2, \sigma_i, \dots, \sigma_{10}$), and ten errors ($\epsilon_1, \epsilon_2, \epsilon_i, \dots, \epsilon_{10}$).

(9) Use the following values to quantify your measurements:

(i) *Accuracy.* Instrument accuracy is the absolute difference between the reference quantity, y_{ref} (or \bar{y}_{ref}), and the arithmetic mean of the ten \bar{y}_i values. Refer to the example of an accuracy calculation in § 1065.602. We recommend that instrument accuracy be within the specifications in Table 1 of § 1065.205.

(ii) *Repeatability.* Repeatability is two times the standard deviation of the ten errors (that is, repeatability = $2 \cdot \sigma_\epsilon$). Refer to the example of a standard-deviation calculation in § 1065.602. We recommend that instrument repeatability be within the specifications in Table 1 of § 1065.205.

(iii) *Noise.* Noise is two times the root-mean-square of the ten standard deviations (that is, noise = $2 \cdot \text{rms}_\sigma$) when the reference signal is a zero-quantity signal. Refer to the example of a root-mean-square calculation in § 1065.602. We recommend that instrument noise be within the specifications in Table 1 of § 1065.205.

Use this value in the noise correction specified in § 1065.657.

(10) You may use a measurement instrument that does not meet the accuracy, repeatability, or noise specifications in Table 1 of § 1065.205, as long as you meet the following criteria:

(i) Your measurement systems meet all the other required calibration, verification, and validation specifications in subparts D, F, and J of this part, as applicable.

(ii) The measurement deficiency does not adversely affect your ability to demonstrate compliance with the applicable standards.

§ 1065.307 Linearity verification.

(a) *Scope and frequency.* Perform a linearity verification on each measurement system listed in Table 1 of this section at least as frequently as indicated in the table, consistent with measurement system manufacturer recommendations and good engineering judgment. Note that this linearity verification may replace requirements we previously referred to as “calibrations”. The intent of a linearity verification is to determine that a measurement system responds proportionally over the measurement range of interest. A linearity verification generally consists of introducing a series of at least 10 reference values to a measurement system. The measurement system quantifies each reference value. The measured values are then collectively compared to the reference values by using a least squares linear regression and the linearity criteria specified in Table 1 of this section.

(b) *Performance requirements.* If a measurement system does not meet the applicable linearity criteria in Table 1 of this section, correct the deficiency by recalibrating, servicing, or replacing components as needed. Before you may use a measurement system that does not meet linearity criteria, you must demonstrate to us that the deficiency does not adversely affect your ability to demonstrate compliance with the applicable standards.

(c) *Procedure.* Use the following linearity verification protocol, or use good engineering judgment to develop a different protocol that satisfies the

intent of this section, as described in paragraph (a) of this section:

(1) In this paragraph (c), we use the letter "y" to denote a generic measured quantity, the superscript over-bar to denote an arithmetic mean (such as \bar{y}), and the subscript "ref" to denote the known or reference quantity being measured.

(2) Operate a measurement system at its specified temperatures, pressures, and flows. This may include any specified adjustment or periodic calibration of the measurement system.

(3) Zero the instrument as you would before an emission test by introducing a zero signal. Depending on the instrument, this may be a zero-concentration gas, a reference signal, a set of reference thermodynamic conditions, or some combination of these. For gas analyzers, use a zero gas that meets the specifications of § 1065.750 and introduce it directly at the analyzer port.

(4) Span the instrument as you would before an emission test by introducing a span signal. Depending on the instrument, this may be a span-concentration gas, a reference signal, a set of reference thermodynamic conditions, or some combination of these. For gas analyzers, use a span gas that meets the specifications of § 1065.750 and introduce it directly at the analyzer port.

(5) After spanning the instrument, check zero with the same signal you used in paragraph (c)(3) of this section. Based on the zero reading, use good engineering judgment to determine whether or not to rezero and or re-span the instrument before proceeding to the next step.

(6) Use instrument manufacturer recommendations and good engineering judgment to select at least 10 reference values, y_{refi} , that are within the range from zero to the highest values expected during emission testing. We recommend selecting a zero reference signal as one of the reference values of the linearity verification.

(7) Use instrument manufacturer recommendations and good engineering judgment to select the order in which you will introduce the series of reference values. For example you may select the reference values randomly to avoid correlation with previous measurements, you may select reference values in ascending or descending order to avoid long settling times of reference signals, or as another example you may select values to ascend and then descend which might incorporate the effects of any instrument hysteresis into the linearity verification.

(8) Generate reference quantities as described in paragraph (d) of this section. For gas analyzers, use gas concentrations known to be within the specifications of § 1065.750 and introduce them directly at the analyzer port.

(9) Introduce a reference signal to the measurement instrument.

(10) Allow time for the instrument to stabilize while it measures the reference value. Stabilization time may include time to purge an instrument and time to account for its response.

(11) At a recording frequency of at least f Hz, specified in Table 1 of § 1065.205, measure the reference value for 30 seconds and record the arithmetic mean of the recorded values, \bar{y}_i . Refer to § 1065.602 for an example of calculating an arithmetic mean.

(12) Repeat steps in paragraphs (c)(9) through (11) of this section until all reference quantities are measured.

(13) Use the arithmetic means y_i , and reference values, y_{refi} , to calculate least-squares linear regression parameters and statistical values to compare to the minimum performance criteria specified in Table 1 of this section. Use the calculations described in § 1065.602.

(d) *Reference signals.* This paragraph (d) describes recommended methods for generating reference values for the linearity-verification protocol in paragraph (c) of this section. Use reference values that simulate actual values, or introduce an actual value and measure it with a reference-measurement system. In the latter case, the reference value is the value reported by the reference-measurement system. Reference values and reference-measurement systems must be NIST-traceable. We recommend using calibration reference quantities that are NIST-traceable within 0.5% uncertainty, if not specified otherwise in other sections of this part 1065. Use the following recommended methods to generate reference values or use good engineering judgment to select a different reference:

(1) *Engine speed.* Run the engine or dynamometer at a series of steady-state speeds and use a strobe, a photo tachometer, or a laser tachometer to record reference speeds.

(2) *Engine torque.* Use a series of calibration weights and a calibration lever arm to simulate engine torque. You may instead use the engine or dynamometer itself to generate a nominal torque that is measured by a reference load cell or proving ring in series with the torque-measurement system. In this case use the reference load cell measurement as the reference value. Refer to § 1065.310 for a torque-

calibration procedure similar to the linearity verification in this section.

(3) *Electrical work.* Use a controlled source of current and a watt-hour standard reference meter. Complete calibration systems that contain a current source and a reference watt-hour meter are commonly used in the electrical power distribution industry and are therefore commercially available.

(4) *Fuel rate.* Operate the engine at a series of constant fuel-flow rates or recirculate fuel back to a tank through the fuel flow meter at different flow rates. Use a gravimetric reference measurement (such as a scale, balance, or mass comparator) at the inlet to the fuel-measurement system. Use a stopwatch or timer to measure the time intervals over which reference masses of fuel are introduced to the fuel measurement system. The reference fuel mass divided by the time interval is the reference fuel flow rate.

(5) *Flow rates—inlet air, dilution air, diluted exhaust, raw exhaust, or sample flow.* Use a reference flow meter with a blower or pump to simulate flow rates. Use a restrictor, diverter valve, a variable-speed blower or a variable-speed pump to control the range of flow rates. Use the reference meter's response as the reference values.

(i) *Reference flow meters.* Because the flow range requirements for these various flows are large, we allow a variety of reference meters. For example, for diluted exhaust flow for a full-flow dilution system, we recommend a reference subsonic venturi flow meter with a restrictor valve and a blower to simulate flow rates. For inlet air, dilution air, diluted exhaust for partial-flow dilution, raw exhaust, or sample flow, we allow reference meters such as critical flow orifices, critical flow venturis, laminar flow elements, master mass flow standards, or Roots meters. Make sure the reference meter is calibrated by the flow-meter manufacturer and its calibration is NIST-traceable. If you use the difference of two flow measurements to determine a net flow rate, you may use one of the measurements as a reference for the other.

(ii) *Reference flow values.* Because the reference flow is not absolutely constant, sample and record values of \dot{n}_{refi} for 30 seconds and use the arithmetic mean of the values, \bar{n}_{ref} , as the reference value. Refer to § 1065.602 for an example of calculating arithmetic mean.

(6) *Gas division.* Use one of the two reference signals: (i) At the outlet of the gas-division system, connect a gas analyzer that meets the linearity

verification described in this section and has not been linearized with the gas divider being verified. For example, verify the linearity of an analyzer using a series of reference analytical gases directly from compressed gas cylinders that meet the specifications of § 1065.750. We recommend using a FID analyzer or a PMD/MPD O₂ analyzer because of their inherent linearity. Operate this analyzer consistent with how you would operate it during an emission test. Connect a span gas to the gas-divider inlet. Use the gas-division

system to divide the span gas with purified air or nitrogen. Select gas divisions that you typically use. Use a selected gas division as the measured value. Use the analyzer response divided by the span gas concentration as the reference gas-division value. Because the instrument response is not absolutely constant, sample and record values of x_{refi} for 30 seconds and use the arithmetic mean of the values \bar{x}_{refi} , as the reference value. Refer to § 1065.602 for an example of calculating arithmetic mean.

(ii) Using good engineering judgment and gas divider manufacturer recommendations, use one or more reference flow meters to verify the measured flow rates of the gas divider.

(7) *Continuous constituent concentration.* For reference values, use a series of gas cylinders of known gas concentration or use a gas-division system that is known to be linear with a span gas. Gas cylinders, gas-division systems, and span gases that you use for reference values must meet the specifications of § 1065.750.

Table 1 of §1065.307—Measurement systems that require linearity verifications

Measurement System	Quantity	Minimum verification frequency ^a	Linearity Criteria			
			$ a_0 $ ^b	a_1 ^c	SEE ^b	r^2
Engine speed	f_n	Within 370 days before testing	$\leq 0.05\% \cdot f_{nmax}$	0.98-1.02	$\leq 2\% \cdot f_{nmax}$	≥ 0.990
Engine torque	T	Within 370 days before testing	$\leq 1\% \cdot T_{max}$	0.98-1.02	$\leq 2\% \cdot T_{max}$	≥ 0.990
Electrical work	W	Within 370 days before testing	$\leq 1\% \cdot W_{max}$	0.98-1.02	$\leq 2\% \cdot W_{max}$	≥ 0.990
Fuel flow rate	\dot{m}	Within 370 days before testing ^d	$\leq 1\% \cdot \dot{m}_{max}$	0.98-1.02 ^e	$\leq 2\% \cdot \dot{m}_{max}$	≥ 0.990
Intake-air flow rate	\dot{n}	Within 370 days before testing ^d	$\leq 1\% \cdot \dot{n}_{max}$	0.98-1.02 ^e	$\leq 2\% \cdot \dot{n}_{max}$	≥ 0.990
Dilution air flow rate	\dot{n}	Within 370 days before testing ^d	$\leq 1\% \cdot \dot{n}_{max}$	0.98-1.02	$\leq 2\% \cdot \dot{n}_{max}$	≥ 0.990
Diluted exhaust flow rate	\dot{n}	Within 370 days before testing ^d	$\leq 1\% \cdot \dot{n}_{min}$	0.98-1.02	$\leq 2\% \cdot \dot{n}_{max}$	≥ 0.990
Raw exhaust flow rate	\dot{n}	Within 185 days before testing ^d	$\leq 1\% \cdot \dot{n}_{max}$	0.98-1.02 ^e	$\leq 2\% \cdot \dot{n}_{max}$	≥ 0.990
Batch sampler flow rates	\dot{n}	Within 370 days before testing ^d	$\leq 1\% \cdot \dot{n}_{max}$	0.98-1.02	$\leq 2\% \cdot \dot{n}_{max}$	≥ 0.990
Gas dividers	x	Within 370 days before testing	$\leq 0.5\% \cdot x_{max}$	0.98-1.02	$\leq 2\% \cdot x_{max}$	≥ 0.990
All gas analyzers	x	Within 35 days before testing	$\leq 0.5\% \cdot x_{max}$	0.99-1.01	$\leq 1\% \cdot x_{max}$	≥ 0.998
PM balance	m	Within 370 days before testing	$\leq 1\% \cdot m_{max}$	0.99-1.01	$\leq 1\% \cdot m_{max}$	≥ 0.998
Stand-alone pressures	p	Within 370 days before testing	$\leq 1\% \cdot p_{max}$	0.99-1.01	$\leq 1\% \cdot p_{max}$	≥ 0.998
Stand-alone temperatures	T	Within 370 days before testing	$\leq 1\% \cdot T_{max}$	0.99-1.01	$\leq 1\% \cdot T_{max}$	≥ 0.998

^a Perform a linearity verification more frequently if the instrument manufacturer recommends it or based on good engineering judgment.

^b "max" refers to the maximum value expected during a test—the maximum value used for the linearity verification.

^c The specified ranges are inclusive. For example, a specified range of 0.98-1.02 for a_1 means $0.98 \leq a_1 \leq 1.02$.

^d These linearity verifications are not required for systems that pass the flow-rate verification for diluted exhaust as described in §1065.341 (the propane check) or for systems that agree within $\pm 2\%$ based on a chemical balance of carbon or oxygen of the intake air, fuel, and exhaust.

^e a_0 and a_1 for these quantities are required only if the actual value of the quantity is required, as opposed to a signal that is only linearly proportional to the actual value.

§ 1065.308 Continuous gas analyzer system-response and updating-recording verification.

(a) *Scope and frequency.* Perform this verification after installing or replacing a gas analyzer that you use for continuous sampling. Also perform this verification if you reconfigure your system in a way that would change system response. For example, perform this verification if you add a significant volume to the transfer lines by increasing their length or adding a filter;

or if you change the frequency at which you sample and record gas-analyzer concentrations.

(b) *Measurement principles.* This test verifies that the updating and recording frequencies match the overall system response to a rapid change in the value of concentrations at the sample probe. Gas analyzer systems must be optimized such that their overall response to a rapid change in concentration is updated and recorded at an appropriate

frequency to prevent loss of information.

(c) *System requirements.* To demonstrate acceptable updating and recording with respect to the system's overall response, use good engineering judgment to select one of the following criteria that your system must meet:

(1) The product of the mean rise time and the frequency at which the system records an updated concentration must be at least 5, and the product of the mean fall time and the frequency at

which the system records an updated concentration must be at least 5. This criteria makes no assumption regarding the frequency content of changes in emission concentrations during emission testing; therefore, it is valid for any testing.

(2) The frequency at which the system records an updated concentration must be at least 5 Hz. This criteria assumes that the frequency content of significant changes in emission concentrations during emission testing do not exceed 1 Hz.

(3) You may use other criteria if we approve the criteria in advance.

(4) For PEMS, you do not have to meet this criteria if your PEMS meets the overall PEMS check in § 1065.920.

(d) *Procedure.* Use the following procedure to verify the response of a continuous gas analyzer system:

(1) *Instrument setup.* Follow the analyzer system manufacturer's start-up and operating instructions. Adjust the system as needed to optimize performance.

(2) *Equipment setup.* Using minimal gas transfer line lengths between all connections, connect a zero-air source to one inlet of a fast-acting 3-way valve (2 inlets, 1 outlet). Using a gas divider, equally blend an NO-CO-CO₂-C₃H₈-CH₄ (balance N₂) span gas with a span gas of NO₂. Connect the gas divider outlet to the other inlet of the 3-way valve. Connect the valve outlet to an overflow at the gas analyzer system's probe or to an overflow fitting between the probe and transfer line to all the analyzers being verified.

(3) *Data collection.* (i) Switch the valve to flow zero gas.

(ii) Allow for stabilization, accounting for transport delays and the slowest instrument's full response.

(iii) Start recording data at the frequency used during emission testing. Each recorded value must be a unique updated concentration measured by the analyzer; you may not use interpolation to increase the number of recorded values.

(iv) Switch the valve to flow the blended span gases.

(v) Allow for transport delays and the slowest instrument's full response.

(vi) Repeat the steps in paragraphs (d)(3)(i) through (v) of this section to record seven full cycles, ending with zero gas flowing to the analyzers.

(vii) Stop recording.

(e) *Performance evaluation.* (1) If you chose to demonstrate compliance with paragraph

(c)(1) of this section, use the data from paragraph (d)(3) of this section to calculate the mean rise time, T_{10-90} , and mean fall time, T_{90-10} , for each of the

analyzers. Multiply these times (in seconds) by their respective recording frequencies in Hertz (1/second). The value for each result must be at least 5. If the value is less than 5, increase the recording frequency or adjust the flows or design of the sampling system to increase the rise time and fall time as needed. You may also configure digital filters to increase rise and fall times.

(2) If a measurement system fails the criterion in paragraph (e)(1) of this section, ensure that signals from the system are updated and recorded at a frequency of at least 5 Hz.

(3) If a measurement system fails the criteria in paragraphs (e)(1) and (2) of this section, you may use the continuous analyzer system only if the deficiency does not adversely affect your ability to show compliance with the applicable standards.

§ 1065.309 Continuous gas analyzer uniform response verification.

(a) *Scope and frequency.* If you use more than one continuous gas analyzer to quantify a gaseous constituent, you must perform this verification. For example, if you determine NMHC as the difference between continuous THC and CH₄ measurements, you must perform this verification on your NMHC measurement system. As another example if you determine NO_x as the sum of separate continuous measurements of NO and NO₂, you must perform this verification on your NO_x measurement system. Also, you must perform this verification if you use one continuous analyzer to apply an interference compensation algorithm to another continuous gas analyzer. Perform this verification after initial installation or major maintenance. Also perform this verification if you reconfigure your system in a way that would change system response. For example, perform this verification if you add a significant volume to the transfer lines by increasing their length or by adding a filter; or if you change the frequency at which you sample and record gas-analyzer concentrations.

(b) *Measurement principles.* This procedure verifies the time-alignment and uniform response of combined continuous gas measurements.

(c) *System requirements.* Demonstrate that combined continuous concentration measurements have a uniform rise and fall during a simultaneous to a step change in both concentrations. During a system response to a rapid change in multiple gas concentrations, demonstrate that the t_{50} times of all combined analyzers all occur at the same recorded second of data or

between the same two recorded seconds of data.

(d) *Procedure.* Use the following procedure to verify the response of a continuous gas analyzer system:

(1) *Instrument setup.* Follow the analyzer system manufacturer's start-up and operating instructions. Adjust the system as needed to optimize performance.

(2) *Equipment setup.* Using minimal gas transfer line lengths between all connections, connect a zero-air source to the inlet of a 100 °C heated line. Connect the heated line outlet to one inlet of a 100 °C heated fast-acting 3-way valve (2 inlets, 1 outlet). Using a gas divider, equally blend an NO-CO-CO₂-C₃H₈-CH₄ (balance N₂) span gas with a span gas of NO₂ (balance N₂). Connect the gas divider outlet to the inlet of a 50 °C heated line. Connect the heated line outlet to the inlet of a 50 °C gas bubbler filled with distilled water. Connect the bubbler outlet to another heated line at 100 °C. Connect the outlet of the 100 °C line to the other inlet of the 3-way valve. Connect the valve outlet to an overflow at the gas analyzer system's probe or to an overflow fitting between the probe and transfer line to all the analyzers being verified.

(3) *Data collection.* (i) Switch the valve to flow zero gas.

(ii) Allow for stabilization, accounting for transport delays and the slowest instrument's full response.

(iii) Start recording data at the frequency used during emission testing.

(iv) Switch the valve to flow span gas.

(v) Allow for transport delays and the slowest instrument's full response.

(vi) Repeat the steps in paragraphs

(d)(3)(i) through (v) of this section to record seven full cycles, ending with zero gas flowing to the analyzers.

(vii) Stop recording.

(e) *Performance evaluations.* Perform the following evaluations:

(1) *Uniform response evaluation.* (i) Calculate the mean rise time, t_{10-90} , mean fall time, t_{90-10} for each analyzer.

(ii) Determine the maximum mean rise and fall times for the slowest responding analyzer in each combination of continuous analyzer signals that you use to determine a single emission concentration.

(iii) If the maximum rise time or fall time is greater than one second, verify that all other gas analyzers combined with it have mean rise and fall times of at least 75% of that analyzer's response.

(iv) If any analyzer has shorter rise or fall times, disperse that signal so that it better matches the rise and fall times of the slowest signal with which it is combined. We recommend that you perform dispersion using SAE 2001-01-

3536 (incorporated by reference in § 1065.1010) as a guide.

(v) Repeat this verification after optimizing your systems to ensure that you dispersed signals correctly. If after repeated attempts at dispersing signals your system still fails this verification, you may use the continuous analyzer system if the deficiency does not adversely affect your ability to show compliance with the applicable standards.

(2) *Time alignment evaluation.* (i) After all signals are adjusted to meet the uniform response evaluation, determine the second at which—or the two seconds between which—each analyzer crossed the midpoint of its response, t_{50} .

(ii) Verify that all combined gas analyzer signals are time-aligned such that all of their t_{50} times occurred at the same second or between the same two seconds in the recorded data.

(iii) If your system fails to meet this criterion, you may change the time alignment of your system and retest the system completely. If after changing the time alignment of your system, some of the t_{50} times still are not aligned, take corrective action by dispersing analyzer signals that have the shortest rise and fall times.

(iv) If some t_{50} times are still not aligned after repeated attempts at dispersion and time alignment, you may use the continuous analyzer system if the deficiency does not adversely affect your ability to show compliance with the applicable standards.

Measurement of Engine Parameters and Ambient Conditions

§ 1065.310 Torque calibration.

(a) *Scope and frequency.* Calibrate all torque-measurement systems including dynamometer torque measurement transducers and systems upon initial installation and after major maintenance. Use good engineering judgment to repeat the calibration. Follow the torque transducer manufacturer's instructions for linearizing your torque sensor's output. We recommend that you calibrate the torque-measurement system with a reference force and a lever arm.

(b) *Recommended procedure.* (1) *Reference force quantification.* Use either a set of dead-weights or a reference meter such as strain gage or a proving ring to quantify the reference force, NIST-traceable within $\pm 0.5\%$ uncertainty.

(2) *Lever-arm length quantification.* Quantify the lever arm length, NIST-traceable within $\pm 0.5\%$ uncertainty. The lever arm's length must be measured from the centerline of the dynamometer

to the point at which the reference force is measured. The lever arm must be perpendicular to gravity (i.e., horizontal), and it must be perpendicular to the dynamometer's rotational axis. Balance the lever arm's torque or quantify its net hanging torque, NIST-traceable within $\pm 1\%$ uncertainty, and account for it as part of the reference torque.

(c) *Dead-weight calibration.* This technique applies a known force by hanging known weights at a known distance along a lever arm. Make sure the weights' lever arm is perpendicular to gravity (i.e., horizontal) and perpendicular to the dynamometer's rotational axis. Apply at least six calibration-weight combinations for each applicable torque-measuring range, spacing the weight quantities about equally over the range. Oscillate or rotate the dynamometer during calibration to reduce frictional static hysteresis. Determine each weight's force by multiplying its NIST-traceable mass by the local acceleration of Earth's gravity (using this equation: force = mass · acceleration). The local acceleration of gravity, a_g , at your latitude, longitude, and elevation may be determined by entering position and elevation data into the U.S. National Oceanographic and Atmospheric Administration's surface gravity prediction Web site at http://www.ngs.noaa.gov/cgi-bin/grav_pdx.prl. If this Web site is unavailable, you may use the equation in § 1065.630, which returns the local acceleration of gravity based on a given latitude. In this case, calculate the reference torque as the weights' reference force multiplied by the lever arm reference length (using this equation: torque = force · lever arm length).

(d) *Strain gage or proving ring calibration.* This technique applies force either by hanging weights on a lever arm (these weights and their lever arm length are not used) or by operating the dynamometer at different torques. Apply at least six force combinations for each applicable torque-measuring range, spacing the force quantities about equally over the range. Oscillate or rotate the dynamometer during calibration to reduce frictional static hysteresis. In this case, the reference torque is determined by multiplying the reference meter force output by its effective lever-arm length, which you measure from the point where the force measurement is made to the dynamometer's rotational axis. Make sure you measure this length perpendicular to gravity (i.e., horizontal) and perpendicular to the dynamometer's rotational axis.

§ 1065.315 Pressure, temperature, and dewpoint calibration.

(a) Calibrate instruments for measuring pressure, temperature, and dewpoint upon initial installation. Follow the instrument manufacturer's instructions and use good engineering judgment to repeat the calibration, as follows:

(1) *Pressure.* We recommend temperature-compensated, digital-pneumatic, or deadweight pressure calibrators, with data-logging capabilities to minimize transcription errors. We recommend using calibration reference quantities that are NIST-traceable within 0.5% uncertainty.

(2) *Temperature.* We recommend digital dry-block or stirred-liquid temperature calibrators, with datalogging capabilities to minimize transcription errors. We recommend using calibration reference quantities that are NIST-traceable within 0.5% uncertainty.

(3) *Dewpoint.* We recommend a minimum of three different temperature-equilibrated and temperature-monitored calibration salt solutions in containers that seal completely around the dewpoint sensor. We recommend using calibration reference quantities that are NIST-traceable within 0.5% uncertainty.

(b) You may remove system components for off-site calibration. We recommend specifying calibration reference quantities that are NIST-traceable within 0.5% uncertainty.

Flow-Related Measurements

§ 1065.320 Fuel-flow calibration.

(a) Calibrate fuel-flow meters upon initial installation. Follow the instrument manufacturer's instructions and use good engineering judgment to repeat the calibration.

(b) You may also develop a procedure based on a chemical balance of carbon or oxygen in engine exhaust.

(c) You may remove system components for off-site calibration. When installing a flow meter with an off-site calibration, we recommend that you consider the effects of the tubing configuration upstream and downstream of the flow meter. We recommend specifying calibration reference quantities that are NIST-traceable within 0.5% uncertainty.

§ 1065.325 Intake-flow calibration.

(a) Calibrate intake-air flow meters upon initial installation. Follow the instrument manufacturer's instructions and use good engineering judgment to repeat the calibration. We recommend using a calibration subsonic venturi, ultrasonic flow meter or laminar flow

element. We recommend using calibration reference quantities that are NIST-traceable within 0.5% uncertainty.

(b) You may remove system components for off-site calibration. When installing a flow meter with an off-site calibration, we recommend that you consider the effects of the tubing configuration upstream and downstream of the flow meter. We recommend specifying calibration reference quantities that are NIST-traceable within 0.5% uncertainty.

(c) If you use a subsonic venturi or ultrasonic flow meter for intake flow measurement, we recommend that you calibrate it as described in § 1065.340.

§ 1065.330 Exhaust-flow calibration.

(a) Calibrate exhaust-flow meters upon initial installation. Follow the instrument manufacturer's instructions and use good engineering judgment to repeat the calibration. We recommend that you use a calibration subsonic venturi or ultrasonic flow meter and simulate exhaust temperatures by incorporating a heat exchanger between the calibration meter and the exhaust-flow meter. If you can demonstrate that the flow meter to be calibrated is insensitive to exhaust temperatures, you may use other reference meters such as laminar flow elements, which are not commonly designed to withstand typical raw exhaust temperatures. We recommend using calibration reference quantities that are NIST-traceable within 0.5% uncertainty.

(b) You may remove system components for off-site calibration. When installing a flow meter with an off-site calibration, we recommend that you consider the effects of the tubing configuration upstream and downstream of the flow meter. We recommend specifying calibration reference quantities that are NIST-traceable within 0.5% uncertainty.

(c) If you use a subsonic venturi or ultrasonic flow meter for raw exhaust flow measurement, we recommend that you calibrate it as described in § 1065.340.

§ 1065.340 Diluted exhaust flow (CVS) calibration.

(a) *Overview.* This section describes how to calibrate flow meters for diluted exhaust constant-volume sampling (CVS) systems.

(b) *Scope and frequency.* Perform this calibration while the flow meter is installed in its permanent position. Perform this calibration after you change any part of the flow configuration upstream or downstream of the flow meter that may affect the flow-meter calibration. Perform this

calibration upon initial CVS installation and whenever corrective action does not resolve a failure to meet the diluted exhaust flow verification (*i.e.*, propane check) in § 1065.341.

(c) *Reference flow meter.* Calibrate a CVS flow meter using a reference flow meter such as a subsonic venturi flow meter, a long-radius ASME/NIST flow nozzle, a smooth approach orifice, a laminar flow element, a set of critical flow venturis, or an ultrasonic flow meter. Use a reference flow meter that reports quantities that are NIST-traceable within $\pm 1\%$ uncertainty. Use this reference flow meter's response to flow as the reference value for CVS flow-meter calibration.

(d) *Configuration.* Do not use an upstream screen or other restriction that could affect the flow ahead of the reference flow meter, unless the flow meter has been calibrated with such a restriction.

(e) *PDP calibration.* Calibrate a positive-displacement pump (PDP) to determine a flow-versus-PDP speed equation that accounts for flow leakage across sealing surfaces in the PDP as a function of PDP inlet pressure. Determine unique equation coefficients for each speed at which you operate the PDP. Calibrate a PDP flow meter as follows:

(1) Connect the system as shown in Figure 1 of this section.

(2) Leaks between the calibration flow meter and the PDP must be less than 0.3% of the total flow at the lowest calibrated flow point; for example, at the highest restriction and lowest PDP-speed point.

(3) While the PDP operates, maintain a constant temperature at the PDP inlet within $\pm 2\%$ of the mean absolute inlet temperature, \bar{T}_{in} .

(4) Set the PDP speed to the first speed point at which you intend to calibrate.

(5) Set the variable restrictor to its wide-open position.

(6) Operate the PDP for at least 3 min to stabilize the system. Continue operating the PDP and record the mean values of at least 30 seconds of sampled data of each of the following quantities:

(i) The mean flow rate of the reference flow meter, \bar{n}_{ref} . This may include several measurements of different quantities, such as reference meter pressures and temperatures, for calculating \bar{n}_{ref} .

(ii) The mean temperature at the PDP inlet, \bar{T}_{in} .

(iii) The mean static absolute pressure at the PDP inlet, \bar{P}_{in} .

(iv) The mean static absolute pressure at the PDP outlet, \bar{P}_{out} .

(v) The mean PDP speed, \bar{f}_{nPDP} .

(7) Incrementally close the restrictor valve to decrease the absolute pressure at the inlet to the PDP, \bar{P}_{in} .

(8) Repeat the steps in paragraphs (e)(6) and (7) of this section to record data at a minimum of six restrictor positions reflecting the full range of possible in-use pressures at the PDP inlet.

(9) Calibrate the PDP by using the collected data and the equations in § 1065.640.

(10) Repeat the steps in paragraphs (e)(6) through (9) of this section for each speed at which you operate the PDP.

(11) Use the equations in § 1065.642 to determine the PDP flow equation for emission testing.

(12) Verify the calibration by performing a CVS verification (*i.e.*, propane check) as described in § 1065.341.

(13) Do not use the PDP below the lowest inlet pressure tested during calibration.

(f) *CFV calibration.* Calibrate a critical-flow venturi (CFV) to verify its discharge coefficient, C_d , at the lowest expected static differential pressure between the CFV inlet and outlet.

Calibrate a CFV flow meter as follows:

(1) Connect the system as shown in Figure 1 of this section.

(2) Start the blower downstream of the CFV.

(3) While the CFV operates, maintain a constant temperature at the CFV inlet within $\pm 2\%$ of the mean absolute inlet temperature, \bar{T}_{in} .

(4) Leaks between the calibration flow meter and the CFV must be less than 0.3% of the total flow at the highest restriction.

(5) Set the variable restrictor to its wide-open position.

(6) Operate the CFV for at least 3 min to stabilize the system. Continue operating the CFV and record the mean values of at least 30 seconds of sampled data of each of the following quantities:

(i) The mean flow rate of the reference flow meter, \bar{n}_{ref} . This may include several measurements of different quantities, such as reference meter pressures and temperatures, for calculating \bar{n}_{ref} .

(ii) Optionally, the mean dewpoint of the calibration air, \bar{T}_{dew} . See § 1065.640 for permissible assumptions.

(iii) The mean temperature at the venturi inlet, \bar{T}_{in} .

(iv) The mean static absolute pressure at the venturi inlet, \bar{P}_{in} .

(v) The mean static differential pressure between the CFV inlet and the CFV outlet, $\Delta\bar{P}_{CFV}$.

(7) Incrementally close the restrictor valve to decrease the absolute pressure at the inlet to the CFV, P_{in} .

(8) Repeat the steps in paragraphs (f)(6) and (7) of this section to record mean data at a minimum of ten restrictor positions, such that you test the fullest practical range of $\Delta\bar{P}_{CFV}$ expected during testing. We do not require that you remove calibration components or CVS components to calibrate at the lowest possible restrictions.

(9) Determine C_d and the lowest allowable $\Delta\bar{P}_{CFV}$ as described in § 1065.640.

(10) Use C_d to determine CFV flow during an emission test. Do not use the CFV below the lowest allowed $\Delta\bar{P}_{CFV}$, as determined in § 1065.640.

(11) Verify the calibration by performing a CVS verification (*i.e.*, propane check) as described in § 1065.341.

(12) If your CVS is configured to operate more than one CFV at a time in parallel, calibrate your CVS by one of the following:

(i) Calibrate every combination of CFVs according to this section and § 1065.640. Refer to § 1065.642 for instructions on calculating flow rates for this option.

(ii) Calibrate each CFV according to this section and § 1065.640. Refer to § 1065.642 for instructions on calculating flow rates for this option.

(g) *SSV calibration.* Calibrate a subsonic venturi (SSV) to determine its

calibration coefficient, C_d , for the expected range of inlet pressures.

Calibrate an SSV flow meter as follows:

(1) Connect the system as shown in Figure 1 of this section.

(2) Start the blower downstream of the SSV.

(3) Leaks between the calibration flow meter and the SSV must be less than 0.3 % of the total flow at the highest restriction.

(4) While the SSV operates, maintain a constant temperature at the SSV inlet within ± 2 % of the mean absolute inlet temperature.

(5) Set the variable restrictor or variable-speed blower to a flow rate greater than the greatest flow rate expected during testing. You may not extrapolate flow rates beyond calibrated values, so we recommend that you make sure the Reynolds number, $Re\#$, at the SSV throat at the greatest calibrated flow rate is greater than the maximum $Re\#$ expected during testing.

(6) Operate the SSV for at least 3 min to stabilize the system. Continue operating the SSV and record the mean of at least 30 seconds of sampled data of each of the following quantities:

(i) The mean flow rate of the reference flow meter, \bar{n}_{ref} . This may include several measurements of different quantities, such as reference meter pressures and temperatures, for calculating \bar{n}_{ref} .

(ii) Optionally, the mean dewpoint of the calibration air, \bar{T}_{dew} . See § 1065.640 for permissible assumptions.

(iii) The mean temperature at the venturi inlet, \bar{T}_{in} .

(iv) The mean static absolute pressure at the venturi inlet, \bar{P}_{in} .

(v) Static differential pressure between the static pressure at the venturi inlet and the static pressure at the venturi throat, $\Delta\bar{P}_{SSV}$.

(7) Incrementally close the restrictor valve or decrease the blower speed to decrease the flow rate.

(8) Repeat the steps in paragraphs (g)(6) and (7) of this section to record data at a minimum of ten flow rates.

(9) Determine a functional form of C_d versus $Re\#$ by using the collected data and the equations in § 1065.640.

(10) Verify the calibration by performing a CVS verification (*i.e.*, propane check) as described in § 1065.341 using the new C_d versus $Re\#$ equation.

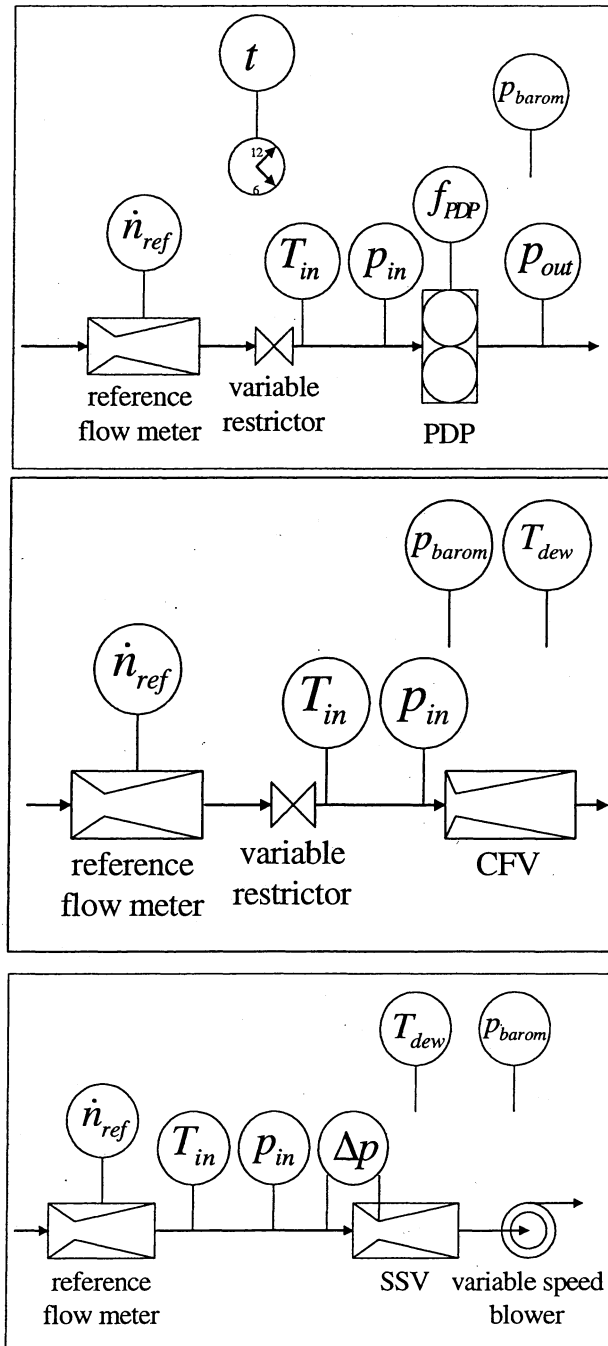
(11) Use the SSV only between the minimum and maximum calibrated flow rates.

(12) Use the equations in § 1065.642 to determine SSV flow during a test.

(h) *Ultrasonic flow meter calibration.*
[Reserved]

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Figure 1 of §1065.340—Schematic diagrams for diluted exhaust flow (CVS) calibration.



BILLING CODE 6560-50-C

§ 1065.341 CVS and batch sampler verification (propane check).

(a) A propane check serves as a CVS verification to determine if there is a discrepancy in measured values of diluted exhaust flow. A propane check also serves as a batch-sampler verification to determine if there is a discrepancy in a batch sampling system that extracts a sample from a CVS, as described in paragraph (g) of this

section. Using good engineering judgment and safe practices, this check may be performed using a gas other than propane, such as CO_2 or CO . A failed propane check might indicate one or more problems that may require corrective action, as follows:

- (1) *Incorrect analyzer calibration.* Recalibrate, repair, or replace the FID analyzer.
- (2) *Leaks.* Inspect CVS tunnel, connections, fasteners, and HC sampling

system, and repair or replace components.

(3) *Poor mixing.* Perform the verification as described in this section while traversing a sampling probe across the tunnel's diameter, vertically and horizontally. If the analyzer response indicates any deviation exceeding $\pm 2\%$ of the mean measured concentration, consider operating the CVS at a higher flow rate or installing a mixing plate or orifice to improve mixing.

(4) *Hydrocarbon contamination in the sample system.* Perform the hydrocarbon-contamination verification as described in § 1065.520.

(5) *Change in CVS calibration.* Perform an in-situ calibration of the CVS flow meter as described in § 1065.340.

(6) *Other problems with the CVS or sampling verification hardware or software.*

Inspect the CVS system, CVS verification hardware, and software for discrepancies. (b) A propane check uses either a reference mass or a reference flow rate of C_3H_8 as a tracer gas in a CVS. Note that if you use a reference flow rate, account for any non-ideal gas behavior of C_3H_8 in the reference flow meter. Refer to § 1065.640 and § 1065.642, which describe how to calibrate and use certain flow meters. Do not use any ideal gas assumptions in § 1065.640 and § 1065.642. The propane check compares the calculated mass of injected C_3H_8 using HC measurements and CVS flow rate measurements with the reference value.

(c) Prepare for the propane check as follows:

(1) If you use a reference mass of C_3H_8 instead of a reference flow rate, obtain a cylinder charged with C_3H_8 . Determine the reference cylinder's mass of C_3H_8 within $\pm 0.5\%$ of the amount of C_3H_8 that you expect to use.

(2) Select appropriate flow rates for the CVS and C_3H_8 .

(3) Select a C_3H_8 injection port in the CVS. Select the port location to be as close as practical to the location where you introduce engine exhaust into the CVS. Connect the C_3H_8 cylinder to the injection system.

(4) Operate and stabilize the CVS.

(5) Preheat or precool any heat exchangers in the sampling system.

(6) Allow heated and cooled components such as sample lines, filters, chillers, and pumps to stabilize at operating temperature.

(7) You may purge the HC sampling system during stabilization.

(8) If applicable, perform a vacuum side leak verification of the HC sampling system as described in § 1065.345.

(9) You may also conduct any other calibrations or verifications on equipment or analyzers.

(d) Zero, span, and verify contamination of the HC sampling system, as follows:

(1) Select the lowest HC analyzer range that can measure the C_3H_8 concentration expected for the CVS and C_3H_8 flow rates.

(2) Zero the HC analyzer using zero air introduced at the analyzer port.

(3) Span the HC analyzer using C_3H_8 span gas introduced at the analyzer port.

(4) Overflow zero air at the HC probe or into a fitting between the HC probe and the transfer line.

(5) Measure the stable HC concentration of the HC sampling system as overflow zero air flows. For batch HC measurement, fill the batch container (such as a bag) and measure the HC overflow concentration.

(6) If the overflow HC concentration exceeds $2 \mu\text{mol/mol}$, do not proceed until contamination is eliminated. Determine the source of the contamination and take corrective action, such as cleaning the system or replacing contaminated portions.

(7) When the overflow HC concentration does not exceed $2 \mu\text{mol/mol}$, record this value as x_{HCpre} and use it to correct for HC contamination as described in § 1065.660.

(e) Perform the propane check as follows:

(1) For batch HC sampling, connect clean storage media, such as evacuated bags.

(2) Operate HC measurement instruments according to the instrument manufacturer's instructions.

(3) If you will correct for dilution air background concentrations of HC, measure and record background HC in the dilution air.

(4) Zero any integrating devices.

(5) Begin sampling, and start any flow integrators.

(6) Release the contents of the C_3H_8 reference cylinder at the rate you selected. If you use a reference flow rate of C_3H_8 , start integrating this flow rate.

(7) Continue to release the cylinder's contents until at least enough C_3H_8 has been released to ensure accurate quantification of the reference C_3H_8 and the measured C_3H_8 .

(8) Shut off the C_3H_8 reference cylinder and continue sampling until you have accounted for time delays due to sample transport and analyzer response.

(9) Stop sampling and stop any integrators.

(f) Perform post-test procedure as follows:

(1) If you used batch sampling, analyze batch samples as soon as practical.

(2) After analyzing HC, correct for contamination and background.

(3) Calculate total C_3H_8 mass based on your CVS and HC data as described in § 1065.650 and § 1065.660, using the molar mass of C_3H_8 , $M_{C_3H_8}$, instead of the effective molar mass of HC, M_{HC} .

(4) If you use a reference mass, determine the cylinder's propane mass within $\pm 0.5\%$ and determine the C_3H_8

reference mass by subtracting the empty cylinder propane mass from the full cylinder propane mass.

(5) Subtract the reference C_3H_8 mass from the calculated mass. If this difference is within $\pm 2.0\%$ of the reference mass, the CVS passes this verification. If not, take corrective action as described in paragraph (a) of this section.

(g) *Batch sampler verification.* You may repeat the propane check to verify a batch sampler, such as a PM secondary dilution system.

(1) Configure the HC sampling system to extract a sample near the location of the batch sampler's storage media (such as a PM filter). If the absolute pressure at this location is too low to extract an HC sample, you may sample HC from the batch sampler pump's exhaust. Use caution when sampling from pump exhaust because an otherwise acceptable pump leak downstream of a batch sampler flow meter will cause a false failure of the propane check.

(2) Repeat the propane check described in this section, but sample HC from the batch sampler.

(3) Calculate C_3H_8 mass, taking into account any secondary dilution from the batch sampler.

(4) Subtract the reference C_3H_8 mass from the calculated mass. If this difference is within $\pm 5\%$ of the reference mass, the batch sampler passes this verification. If not, take corrective action as described in paragraph (a) of this section.

§ 1065.345 Vacuum-side leak verification.

(a) *Scope and frequency.* Upon initial sampling system installation, after major maintenance, and before each test according to subpart F of this part for laboratory tests and according to subpart J of this part for field tests, verify that there are no significant vacuum-side leaks using one of the leak tests described in this section.

(b) *Measurement principles.* A leak may be detected either by measuring a small amount of flow when there should be zero flow, or by detecting the dilution of a known concentration of span gas when it flows through the vacuum side of a sampling system.

(c) *Low-flow leak test.* Test a sampling system for low-flow leaks as follows:

(1) Seal the probe end of the system by taking one of the following steps:

(i) Cap or plug the end of the sample probe.

(ii) Disconnect the transfer line at the probe and cap or plug the transfer line.

(iii) Close a leak-tight valve in-line between a probe and transfer line.

(2) Operate all vacuum pumps. After stabilizing, verify that the flow through

the vacuum-side of the sampling system is less than 0.5 % of the system's normal in-use flow rate. You may estimate typical analyzer and bypass flows as an approximation of the system's normal in-use flow rate.

(d) *Dilution-of-span-gas leak test.* Test any analyzer, other than a FID, for dilution of span gas as follows, noting that this configuration requires an overflow span gas system:

(1) Prepare a gas analyzer as you would for emission testing.

(2) Supply span gas to the analyzer port and verify that it measures the span gas concentration within its expected measurement accuracy and repeatability.

(3) Route overflow span gas to one of the following locations in the sampling system:

(i) The end of the sample probe.

(ii) Disconnect the transfer line at the probe connection, and overflow the span gas at the open end of the transfer line.

(iii) A three-way valve installed in-line between a probe and its transfer line, such as a system overflow zero and span port.

(4) Verify that the measured overflow span gas concentration is within the measurement accuracy and repeatability of the analyzer. A measured value lower than expected indicates a leak, but a value higher than expected may indicate a problem with the span gas or the analyzer itself. A measured value higher than expected does not indicate a leak.

CO and CO₂ Measurements

§ 1065.350 H₂O interference verification for CO₂ NDIR analyzers.

(a) *Scope and frequency.* If you measure CO₂ using an NDIR analyzer, verify the amount of H₂O interference after initial analyzer installation and after major maintenance.

(b) *Measurement principles.* H₂O can interfere with an NDIR analyzer's response to CO₂.

If the NDIR analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously conduct these other measurements to test the compensation algorithms during the analyzer interference verification.

(c) *System requirements.* A CO₂ NDIR analyzer must have an H₂O interference that is within $\pm 2\%$ of the flow-weighted mean CO₂ concentration expected at the standard, though we strongly recommend a lower interference that is within $\pm 1\%$.

(d) *Procedure.* Perform the interference verification as follows:

(1) Start, operate, zero, and span the CO₂ NDIR analyzer as you would before an emission test.

(2) Create a water-saturated test gas by bubbling zero air that meets the specifications in § 1065.750 through distilled water in a sealed vessel at (25 ± 10) °C.

(3) Introduce the water-saturated test gas upstream of any sample dryer, if one is used during testing.

(4) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyzer response.

(5) While the analyzer measures the sample's concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of this data. The analyzer meets the interference verification if this value is within $\pm 2\%$ of the flow-weighted mean concentration of CO₂ expected at the standard.

(e) *Exceptions.* The following exceptions apply:

(1) You may omit this verification if you can show by engineering analysis that for your CO₂ sampling system and your emission-calculation procedures, the H₂O interference for your CO₂ NDIR analyzer always affects your brake-specific emission results within $\pm 0.5\%$ of each of the applicable standards.

(2) You may use a CO₂ NDIR analyzer that you determine does not meet this verification, as long as you try to correct the problem and the measurement deficiency does not adversely affect your ability to show that engines comply with all applicable emission standards.

§ 1065.355 H₂O and CO₂ interference verification for CO NDIR analyzers.

(a) *Scope and frequency.* If you measure CO using an NDIR analyzer, verify the amount of H₂O and CO₂ interference after initial analyzer installation and after major maintenance.

(b) *Measurement principles.* H₂O and CO₂ can positively interfere with an NDIR analyzer by causing a response similar to CO. If the NDIR analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously conduct these other measurements to test the compensation algorithms during the analyzer interference verification.

(c) *System requirements.* A CO NDIR analyzer must have combined H₂O and CO₂ interference that is within $\pm 2\%$ of the flow-weighted mean concentration of CO expected at the standard, though

we strongly recommend a lower interference that is within $\pm 1\%$.

(d) *Procedure.* Perform the interference verification as follows:

(1) Start, operate, zero, and span the CO NDIR analyzer as you would before an emission test.

(2) Create a water-saturated CO₂ test gas by bubbling a CO₂ span gas through distilled water in a sealed vessel at (25 ± 10) °C.

(3) Introduce the water-saturated CO₂ test gas upstream of any sample dryer, if one is used during testing.

(4) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyzer response.

(5) While the analyzer measures the sample's concentration, record its output for 30 seconds. Calculate the arithmetic mean of this data.

(6) Multiply this mean value by the ratio of expected CO₂ to span gas CO₂ concentration. In other words, estimate the flow-weighted mean dry concentration of CO₂ expected during testing, and then divide this value by the concentration of CO₂ in the span gas used for this verification. Then multiply this ratio by the mean value recorded during this verification.

(7) The analyzer meets the interference verification if the result of paragraph (d)(6) of this section is within $\pm 2\%$ of the flow-weighted mean concentration of CO expected at the standard.

(e) *Exceptions.* The following exceptions apply:

(1) You may omit this verification if you can show by engineering analysis that for your CO sampling system and your emission calculations procedures, the combined CO₂ and H₂O interference for your CO NDIR analyzer always affects your brake-specific CO emission results within $\pm 0.5\%$ of the applicable CO standard. (2) You may use a CO NDIR analyzer that you determine does not meet this verification, as long as you try to correct the problem and the measurement deficiency does not adversely affect your ability to show that engines comply with all applicable emission standards.

Hydrocarbon Measurements

§ 1065.360 FID optimization and verification.

(a) *Scope and frequency.* For all FID analyzers perform the following steps:

(1) Calibrate a FID upon initial installation. Repeat the calibration as needed using good engineering judgment.

(2) Optimize a FID's response to various hydrocarbons after initial

analyzer installation and after major maintenance.

(3) Determine a FID's methane (CH_4) response factor after initial analyzer installation and after major maintenance.

(4) Verify methane (CH_4) response within 185 days before testing.

(b) *Calibration.* Use good engineering judgment to develop a calibration procedure, such as one based on the FID-analyzer manufacturer's instructions and recommended frequency for calibrating the FID.

Alternately, you may remove system components for off-site calibration. Calibrate using C_3H_8 calibration gases that meet the specifications of § 1065.750. We recommend FID analyzer zero and span gases that contain approximately the flow-weighted mean concentration of O_2 expected during testing. If you use a FID to measure methane (CH_4) downstream of a nonmethane cutter, you may calibrate that FID using CH_4 calibration gases with the cutter. Regardless of the calibration gas composition, calibrate on a carbon number basis of one (C_1). For example, if you use a C_3H_8 span gas of concentration $200 \mu\text{mol/mol}$, span the FID to respond with a value of $600 \mu\text{mol/mol}$.

(c) *FID response optimization.* Use good engineering judgment for initial instrument start-up and basic operating adjustment using FID fuel and zero air. Heated FIDs must be within their required operating temperature ranges. Optimize FID response at the most common analyzer range expected during emission testing. Optimization involves adjusting flows and pressures of FID fuel, burner air, and sample to minimize response variations to various hydrocarbon species in the exhaust. Use good engineering judgment to trade off peak FID response to propane calibration gases to achieve minimal response variations to different hydrocarbon species. For an example of trading off response to propane for relative responses to other hydrocarbon species, see SAE 770141 (incorporated by reference in § 1065.1010). Determine the optimum flow rates for FID fuel, burner air, and sample and record them for future reference.

(d) *CH_4 response factor determination.* Since FID analyzers generally have a different response to CH_4 versus C_3H_8 , determine each FID analyzer's CH_4 response factor, RF_{CH_4} , after FID optimization. Use the most recent RF_{CH_4} measured according to this section in the calculations for HC determination described in § 1065.660 to compensate for CH_4 response. Determine RF_{CH_4} as follows, noting that

you do not determine RF_{CH_4} for FIDs that are calibrated and spanned using CH_4 with a nonmethane cutter:

(1) Select a C_3H_8 span gas that meets the specifications of § 1065.750. Record the C_3H_8 concentration of the gas.

(2) Select a CH_4 span gas that meets the specifications of § 1065.750. Record the CH_4 concentration of the gas.

(3) Start and operate the FID analyzer according to the manufacturer's instructions.

(4) Confirm that the FID analyzer has been calibrated using C_3H_8 . Calibrate on a carbon number basis of one (C_1). For example, if you use a C_3H_8 span gas of concentration $200 \mu\text{mol/mol}$, span the FID to respond with a value of $600 \mu\text{mol/mol}$.

(5) Zero the FID with a zero gas that you use for emission testing.

(6) Span the FID with the C_3H_8 span gas that you selected under paragraph (d)(1) of this section.

(7) Introduce at the sample port of the FID analyzer, the CH_4 span gas that you selected under paragraph (d)(2) of this section.

(8) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the analyzer and to account for its response.

(9) While the analyzer measures the CH_4 concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of these values.

(10) Divide the mean measured concentration by the recorded span concentration of the CH_4 calibration gas. The result is the FID analyzer's response factor for CH_4 , RF_{CH_4} .

(e) *FID methane (CH_4) response verification.* If the value of RF_{CH_4} from paragraph (d) of this section is within $\pm 5.0\%$ of its most recent previously determined value, the FID passes the methane response verification. For example, if the most recent previous value for RF_{CH_4} was 1.05 and it changed by +0.05 to become 1.10 or it changed by -0.05 to become 1.00, either case would be acceptable because +4.8% is less than +5.0%.

(1) Verify that the pressures and flow rates of FID fuel, burner air, and sample are each within $\pm 0.5\%$ of their most recent previously recorded values, as described in paragraph (c) of this section. You may adjust these flow rates as necessary. Determine a new RF_{CH_4} as described in paragraph (d) of this section.

(2) If RF_{CH_4} is still not within $\pm 5.0\%$ of its most recently determined value after adjusting flow rates, re-optimize the FID response as described in paragraph (c) of this section.

(3) Determine a new RF_{CH_4} as described in paragraph (d) of this

section. Use this new value of RF_{CH_4} in the calculations for HC determination, as described in § 1065.660.

§ 1065.362 Non-stoichiometric raw exhaust FID O_2 interference verification.

(a) *Scope and frequency.* If you use FID analyzers for raw exhaust measurements from engines that operate in a non-stoichiometric mode of combustion (e.g., compression-ignition, lean-burn), verify the amount of FID O_2 interference upon initial installation and after major maintenance.

(b) *Measurement principles.* Changes in O_2 concentration in raw exhaust can affect FID response by changing FID flame temperature. Optimize FID fuel, burner air, and sample flow to meet this verification. Verify FID performance with the compensation algorithms for FID O_2 interference that you have active during an emission test.

(c) *System requirements.* Any FID analyzer used during testing must meet the FID O_2 interference verification according to the procedure in this section.

(d) *Procedure.* Determine FID O_2 interference as follows:

(1) Select two span reference gases that meet the specifications in § 1065.750 and contain C_3H_8 near 100% of span for HC. You may use CH_4 span reference gases for FIDs calibrated on CH_4 with a nonmethane cutter. Select the two balance gas concentrations such that the concentrations of O_2 and N_2 represent the minimum and maximum O_2 concentrations expected during testing.

(2) Confirm that the FID analyzer meets all the specifications of § 1065.360.

(3) Start and operate the FID analyzer as you would before an emission test. Regardless of the FID burner's air source during testing, use zero air as the FID burner's air source for this verification.

(4) Zero the FID analyzer using the zero gas used during emission testing.

(5) Span the FID analyzer using the span gas used during emission testing.

(6) Check the zero response of the FID analyzer using the zero gas used during emission testing. If the mean zero response of 30 seconds of sampled data is within $\pm 0.5\%$ of the span reference value used in paragraph (d)(5) of this section, then proceed to the next step; otherwise restart the procedure at paragraph (d)(4) of this section.

(7) Check the analyzer response using the span gas that has the minimum concentration of O_2 expected during testing. Record the mean response of 30 seconds of stabilized sample data as $X_{\text{O}_2\text{minHC}}$.

(8) Check the zero response of the FID analyzer using the zero gas used during

emission testing. If the mean zero response of 30 seconds of stabilized sample data is within $\pm 0.5\%$ of the span reference value used in paragraph (d)(5) of this section, then proceed to the next step; otherwise restart the procedure at paragraph (d)(4) of this section.

(9) Check the analyzer response using the span gas that has the maximum concentration of O_2 expected during testing. Record the mean response of 30 seconds of stabilized sample data as X_{O_2maxHC} .

(10) Check the zero response of the FID analyzer using the zero gas used during emission testing. If the mean zero response of 30 seconds of stabilized sample data is within $\pm 0.5\%$ of the span reference value used in paragraph (d)(5) of this section, then proceed to the next step; otherwise restart the procedure at paragraph (d)(4) of this section.

(11) Calculate the percent difference between X_{O_2maxHC} and its reference gas concentration. Calculate the percent difference between X_{O_2minHC} and its reference gas concentration. Determine the maximum percent difference of the two. This is the O_2 interference.

(12) If the O_2 interference is within $\pm 1.5\%$, then the FID passes the O_2 interference check; otherwise perform one or more of the following to address the deficiency:

(i) Select zero and span gases for emission testing that contain higher or lower O_2 concentrations.

(ii) Adjust FID burner air, fuel, and sample flow rates. Note that if you adjust these flow rates to meet the O_2 interference verification, you must re-verify with the adjusted flow rates that the FID meets the CH_4 response factor verification according to § 1065.360.

(iii) Repair or replace the FID.

(iv) Demonstrate that the deficiency does not adversely affect your ability to demonstrate compliance with the applicable emission standards.

§ 1065.365 Nonmethane cutter penetration fractions.

(a) *Scope and frequency.* If you use a FID analyzer and a nonmethane cutter (NMC) to measure methane (CH_4), determine the nonmethane cutter's penetration fractions of methane, PF_{CH_4} , and ethane, $PF_{C_2H_6}$. Perform this verification after installing the nonmethane cutter. Repeat this verification within 185 days of testing to verify that the catalytic activity of the cutter has not deteriorated. Note that because nonmethane cutters can deteriorate rapidly and without warning if they are operated outside of certain ranges of gas concentrations and outside of certain temperature ranges, good engineering judgment may dictate that

you determine a nonmethane cutter's penetration fractions more frequently.

(b) *Measurement principles.* A nonmethane cutter is a heated catalyst that removes nonmethane hydrocarbons from the exhaust stream before the FID analyzer measures the remaining hydrocarbon concentration. An ideal nonmethane cutter would have PF_{CH_4} of 1.000, and the penetration fraction for all other hydrocarbons would be 0.000, as represented by $PF_{C_2H_6}$. The emission calculations in § 1065.660 use this section's measured values of PF_{CH_4} and $PF_{C_2H_6}$ to account for less than ideal NMC performance.

(c) *System requirements.* We do not limit NMC penetration fractions to a certain range. However, we recommend that you optimize a nonmethane cutter by adjusting its temperature to achieve $PF_{CH_4} > 0.95$ and $PF_{C_2H_6} < 0.02$ as determined by paragraphs (d) and (e) of this section, as applicable. If we use a nonmethane cutter for testing, it will meet this recommendation. If adjusting NMC temperature does not result in achieving both of these specifications simultaneously, we recommend that you replace the catalyst material.

Use the most recently determined penetration values from this section to calculate HC emissions according to § 1065.660 and § 1065.665 as applicable.

(d) *Procedure for a FID calibrated with the NMC.* If your FID arrangement is such that a FID is always calibrated to measure CH_4 with the NMC, then span that FID with the NMC cutter using a CH_4 span gas, set that FID's CH_4 penetration fraction, PF_{CH_4} , equal to 1.0 for all emission calculations, and determine its ethane (C_2H_6) penetration fraction, $PF_{C_2H_6}$, as follows:

(1) Select a CH_4 gas mixture and a C_2H_6 analytical gas mixture and ensure that both mixtures meet the specifications of § 1065.750. Select a CH_4 concentration that you would use for spanning the FID during emission testing and select a C_2H_6 concentration that is typical of the peak NMHC concentration expected at the hydrocarbon standard or equal to THC analyzer's span value.

(2) Start, operate, and optimize the nonmethane cutter according to the manufacturer's instructions, including any temperature optimization.

(3) Confirm that the FID analyzer meets all the specifications of § 1065.360.

(4) Start and operate the FID analyzer according to the manufacturer's instructions.

(5) Zero and span the FID with the cutter and use CH_4 span gas to span the FID with the cutter. Note that you must span the FID on a C_1 basis. For example,

if your span gas has a CH_4 reference value of $100 \mu\text{mol}$, the correct FID response to that span gas is $100 \mu\text{mol}$ because there is one carbon atom per CH_4 molecule.

(6) Introduce the C_2H_6 analytical gas mixture upstream of the nonmethane cutter.

(7) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the nonmethane cutter and to account for the analyzer's response.

(8) While the analyzer measures a stable concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of these data points.

(9) Divide the mean by the reference value of C_2H_6 , converted to a C_1 basis. The result is the C_2H_6 penetration fraction, $PF_{C_2H_6}$. Use this penetration fraction and the CH_4 penetration fraction, which is set equal to 1.0, in emission calculations according to § 1065.660 or § 1065.665, as applicable.

(e) *Procedure for a FID calibrated by bypassing the NMC.* If you use a FID with an NMC that is calibrated by bypassing the NMC, determine penetration fractions as follows:

(1) Select CH_4 and C_2H_6 analytical gas mixtures that meet the specifications of § 1065.750 with the CH_4 concentration typical of its peak concentration expected at the hydrocarbon standard and the C_2H_6 concentration typical of the peak total hydrocarbon (THC) concentration expected at the hydrocarbon standard or the THC analyzer span value.

(2) Start and operate the nonmethane cutter according to the manufacturer's instructions, including any temperature optimization.

(3) Confirm that the FID analyzer meets all the specifications of § 1065.360.

(4) Start and operate the FID analyzer according to the manufacturer's instructions.

(5) Zero and span the FID as you would during emission testing. Span the FID by bypassing the cutter and by using C_3H_8 span gas to span the FID. Note that you must span the FID on a C_1 basis. For example, if your span gas has a propane reference value of $100 \mu\text{mol}$, the correct FID response to that span gas is $300 \mu\text{mol}$ because there are three carbon atoms per C_3H_8 molecule.

(6) Introduce the C_2H_6 analytical gas mixture upstream of the nonmethane cutter.

(7) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the nonmethane cutter and to account for the analyzer's response.

(8) While the analyzer measures a stable concentration, record 30 seconds of sampled data. Calculate the arithmetic mean of these data points.

(9) Reroute the flow path to bypass the nonmethane cutter, introduce the C₂H₆ analytical gas mixture to the bypass, and repeat the steps in paragraphs (e)(7) through (8) of this section.

(10) Divide the mean C₂H₆ concentration measured through the nonmethane cutter by the mean concentration measured after bypassing the nonmethane cutter. The result is the C₂H₆ penetration fraction, PF_{C₂H₆}. Use this penetration fraction according to § 1065.660 or § 1065.665, as applicable.

(11) Repeat the steps in paragraphs (e)(6) through (10) of this section, but with the CH₄ analytical gas mixture instead of C₂H₆. The result will be the CH₄ penetration fraction, PF_{CH₄}. Use this penetration fraction according to § 1065.660 or § 1065.665, as applicable.

NO_x Measurements

§ 1065.370 CLD CO₂ and H₂O quench verification.

(a) *Scope and frequency.* If you use a CLD analyzer to measure NO_x, verify the amount of H₂O and CO₂ quench after installing the CLD analyzer and after major maintenance.

(b) *Measurement principles.* H₂O and CO₂ can negatively interfere with a CLD's NO_x response by collisional quenching, which inhibits the chemiluminescent reaction that a CLD utilizes to detect NO_x. The calculations in § 1065.672 for H₂O quench account for the water vapor in humidified NO span gas. The procedure and the calculations scale the quench results to the water vapor and CO₂ concentrations expected during testing. If the CLD analyzer uses quench compensation algorithms that utilize H₂O and/or CO₂ measurement instruments, use these instruments to measure H₂O and/or CO₂ and evaluate quench with the compensation algorithms applied.

(c) *System requirements.* A CLD analyzer must have a combined H₂O and CO₂ quench of ±2% or less, though we strongly recommend a quench of ±1% or less. Combined quench is the sum of the CO₂ quench determined as described in paragraph (d) of this section, plus the H₂O quench determined in paragraph (e) of this section.

(d) *CO₂ quench verification procedure.* Use the following method to determine CO₂ quench, or use good engineering judgment to develop a different protocol:

(1) Use PTFE tubing to make necessary connections.

(2) Connect a pressure-regulated CO₂ span gas to one of the inlets of a three-way valve made of 300 series stainless steel. Use a CO₂ span gas that meets the specifications of § 1065.750 and attempt to use a concentration that is approximately twice the maximum CO₂ concentration expected to enter the CLD sample port during testing, if available.

(3) Connect a pressure-regulated purified N₂ gas to the valve's other inlet. Use a purified N₂ gas that meets the specifications of § 1065.750.

(4) Connect the valve's single outlet to the balance-gas port of a gas divider that meets the specifications in § 1065.248.

(5) Connect a pressure-regulated NO span gas to the span-port of the gas divider. Use an NO span gas that meets the specifications of § 1065.750. Attempt to use an NO concentration that is approximately twice the maximum NO concentration expected during testing, if available.

(6) Configure the gas divider such that nearly equal amounts of the span gas and balance gas are blended with each other. Apply viscosity corrections as necessary to appropriately ensure correct gas division.

(7) While flowing balance and span gases through the gas divider, stabilize the CO₂ concentration downstream of the gas divider and measure the CO₂ concentration with an NDIR analyzer that has been prepared for emission testing. Record this concentration, X_{CO₂meas}, and use it in the quench verification calculations in § 1065.675.

(8) Measure the NO concentration downstream of the gas divider. If the CLD has an operating mode in which it detects NO-only, as opposed to total NO_x, operate the CLD in the NO-only operating mode. Record this concentration, X_{NO,CO₂}, and use it in the quench verification calculations in § 1065.675.

(9) Switch the three-way valve so 100% purified N₂ flows to the gas divider's balance-port inlet. Monitor the CO₂ at the gas divider's outlet until its concentration stabilizes at zero.

(10) Measure NO concentration at the gas divider's outlet. Record this value, X_{NO,N₂}, and use it in the quench verification calculations in § 1065.675.

(11) Use the values recorded according to this paragraph (d) of this section and paragraph (e) of this section to calculate quench as described in § 1065.675.

(e) *H₂O quench verification procedure.* Use the following method to determine H₂O quench, or use good engineering judgment to develop a different protocol:

(1) Use PTFE tubing to make necessary connections.

(2) If the CLD has an operating mode in which it detects NO-only, as opposed to total NO_x, operate the CLD in the NO-only operating mode.

(3) Measure an NO calibration span gas that meets the specifications of § 1065.750 and is near the maximum concentration expected during testing. Record this concentration, X_{NOdry}.

(4) Humidify the gas by bubbling it through distilled water in a sealed vessel. We recommend that you humidify the gas to the highest sample dewpoint that you estimate during emission sampling. Regardless of the humidity during this test, the quench verification calculations in § 1065.675 scale the recorded quench to the highest dewpoint that you expect entering the CLD sample port during emission sampling.

(5) If you do not use any sample dryer for NO_x during emissions testing, record the vessel water temperature as T_{dew}, and its pressure as P_{total} and use these values according to § 1065.645 to calculate the amount of water entering the CLD sample port, X_{H₂Omeas}. If you do use a sample dryer for NO_x during emissions testing, measure the humidity of the sample just upstream of the CLD sample port and use the measured humidity according to § 1065.645 to calculate the amount of water entering the CLD sample port, X_{H₂Omeas}.

(6) To prevent subsequent condensation, make sure that any humidified sample will not be exposed to temperatures lower than T_{dew} during transport from the sealed vessel's outlet to the CLD. We recommend using heated transfer lines.

(7) Introduce the humidified sample upstream of any sample dryer, if one is used.

(8) Use the CLD to measure the NO concentration of the humidified span gas and record this value, X_{NOwet}.

(9) Use the recorded values from this paragraph (e) to calculate the quench as described in § 1065.675.

(10) Use the values recorded according to this paragraph (e) of this section and paragraph (d) of this section to calculate quench as described in § 1065.675.

(f) *Corrective action.* If the sum of the H₂O quench plus the CO₂ quench is not within ±2%, take corrective action by repairing or replacing the analyzer. Before using a CLD for emission testing, demonstrate that the corrective action resulted in a value within ±2% combined quench.

(g) *Exceptions.* The following exceptions apply:

(1) You may omit this verification if you can show by engineering analysis that for your NO_x sampling system and

your emission calculations procedures, the the combined CO₂ and H₂O interference for your NO_x CLD analyzer always affects your brake-specific NO_x emission results within no more than $\pm 1.0\%$ of the applicable NO_x standard.

(2) You may use a NO_x CLD analyzer that you determine does not meet this verification, as long as you try to correct the problem and the measurement deficiency does not adversely affect your ability to show that engines comply with all applicable emission standards.

§ 1065.372 NDUV analyzer HC and H₂O interference verification.

(a) *Scope and frequency.* If you measure NO_x using an NDUV analyzer, verify the amount of H₂O and hydrocarbon interference after initial analyzer installation and after major maintenance.

(b) *Measurement principles.* Hydrocarbons and H₂O can positively interfere with an NDUV analyzer by causing a response similar to NO_x. If the NDUV analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously conduct such measurements to test the algorithms during the analyzer interference verification.

(c) *System requirements.* A NO_x NDUV analyzer must have combined H₂O and HC interference within $\pm 2\%$ of the flow-weighted mean concentration of NO_x expected at the standard, though we strongly recommend keeping interference within $\pm 1\%$.

(d) *Procedure.* Perform the interference verification as follows:

(1) Start, operate, zero, and span the NO_x NDUV analyzer according to the instrument manufacturer's instructions.

(2) We recommend that you extract engine exhaust to perform this verification. Use a CLD that meets the specifications of subpart C of this part to quantify NO_x in the exhaust. Use the CLD response as the reference value. Also measure HC in the exhaust with a FID analyzer that meets the specifications of subpart C of this part. Use the FID response as the reference hydrocarbon value.

(3) Upstream of any sample dryer, if one is used during testing, introduce the engine exhaust to the NDUV analyzer.

(4) Allow time for the analyzer response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyzer response.

(5) While all analyzers measure the sample's concentration, record 30 seconds of sampled data, and calculate

the arithmetic means for the three analyzers.

(6) Subtract the CLD mean from the NDUV mean.

(7) Multiply this difference by the ratio of the flow-weighted mean HC concentration expected at the standard to the HC concentration measured during the verification. The analyzer meets the interference verification of this section if this result is within $\pm 2\%$ of the HC concentration expected at the standard.

(e) *Exceptions.* The following exceptions apply:

(1) You may omit this verification if you can show by engineering analysis that for your NO_x sampling system and your emission calculations procedures, the the combined HC and H₂O interference for your NO_x NDUV analyzer always affects your brake-specific NO_x emission results by less than 0.5% of the applicable NO_x standard.

(2) You may use a NO_x NDUV analyzer that you determine does not meet this verification, as long as you try to correct the problem and the measurement deficiency does not adversely affect your ability to show that engines comply with all applicable emission standards.

§ 1065.376 Chiller NO₂ penetration.

(a) *Scope and frequency.* If you use a chiller to dry a sample upstream of a NO_x measurement instrument, but you don't use an NO₂-to-NO converter upstream of the chiller, you must perform this verification for chiller NO₂ penetration. Perform this verification after initial installation and after major maintenance.

(b) *Measurement principles.* A chiller removes water, which can otherwise interfere with a NO_x measurement. However, liquid water in an improperly designed chiller can remove NO₂ from the sample. If a chiller is used without an NO₂-to-NO converter upstream, it could therefore remove NO₂ from the sample prior NO_x measurement.

(c) *System requirements.* A chiller must allow for measuring at least 95% of the total NO₂ at the maximum expected concentration of NO₂.

(d) *Procedure.* Use the following procedure to verify chiller performance:

(1) *Instrument setup.* Follow the analyzer and chiller manufacturers' start-up and operating instructions. Adjust the analyzer and chiller as needed to optimize performance.

(2) *Equipment setup.* Connect an ozonator's inlet to a zero-air or oxygen source and connect its outlet to one port of a three-way tee fitting. Connect an NO span gas to another port of the tee.

Connect a heated line at 100 °C to the last port, and connect a heated three-way tee to the other end of the line. Connect a dewpoint generator, set at a dewpoint of 50 °C, to one end of a heated line at 100 °C. Connect the other end of the line to the heated tee and connect a third 100 °C heated line to the chiller inlet. Provide an overflow vent line at the chiller inlet.

(3) *Adjustments.* For the following adjustment steps, set the analyzer to measure only NO (*i.e.*, NO mode), or only read the NO channel of the analyzer:

(i) With the dewpoint generator and the ozonator off, adjust the NO and zero-gas flows so the NO concentration at the analyzer is at least two times the peak total NO_x concentration expected during testing at the standard. Verify that gas is flowing out of the overflow vent line.

(ii) Turn on the dewpoint generator and adjust its flow so the NO concentration at the analyzer is at least at the peak total NO_x concentration expected during testing at the standard. Verify that gas is flowing out of the overflow vent line.

(iii) Turn on the ozonator and adjust the ozonator so the NO concentration measured by the analyzer decreases by the same amount as the maximum concentration of NO₂ expected during testing. This ensures that the ozonator is generating NO₂ at the maximum concentration expected during testing.

(4) *Data collection.* Maintain the ozonator adjustment in paragraph (d)(3) of this section, and keep the NO_x analyzer in the NO only mode or only read the NO channel of the analyzer.

(i) Allow for stabilization, accounting only for transport delays and instrument response.

(ii) Calculate the mean of 30 seconds of sampled data from the analyzer and record this value as NO_{ref}.

(iii) Switch the analyzer to the total NO_x mode, (that is, sum the NO and NO₂ channels of the analyzer) and allow for stabilization, accounting only for transport delays and instrument response.

(iv) Calculate the mean of 30 seconds of sampled data from the analyzer and record this value as NO_{xmeas}.

(v) Turn off the ozonator and allow for stabilization, accounting only for transport delays and instrument response.

(vi) Calculate the mean of 30 seconds of sampled data from the analyzer and record this value as NO_{xref}.

(5) *Performance evaluation.* Divide the quantity of (NO_{xmeas} - NO_{ref}) by the quantity of (NO_{xref} - NO_{ref}). If the result

is less than 95%, repair or replace the chiller.

(e) *Exceptions.* The following exceptions apply:

(1) You may omit this verification if you can show by engineering analysis that for your NO_x sampling system and your emission calculations procedures, the chiller always affects your brake-specific NO_x emission results by less than 0.5% of the applicable NO_x standard.

(2) You may use a chiller that you determine does not meet this verification, as long as you try to correct the problem and the measurement deficiency does not adversely affect your ability to show that engines comply with all applicable emission standards.

§ 1065.378 NO₂-to-NO converter conversion verification.

(a) *Scope and frequency.* If you use an analyzer that measures only NO to determine NO_x, you must use an NO₂-to-NO converter upstream of the analyzer. Perform this verification after installing the converter, after major maintenance and within 35 days before an emission test. This verification must be repeated at this frequency to verify that the catalytic activity of the NO₂-to-NO converter has not deteriorated.

(b) *Measurement principles.* An NO₂-to-NO converter allows an analyzer that measures only NO to determine total NO_x by converting the NO₂ in exhaust to NO.

(c) *System requirements.* An NO₂-to-NO converter must allow for measuring at least 95% of the total NO₂ at the maximum expected concentration of NO₂.

(d) *Procedure.* Use the following procedure to verify the performance of a NO₂-to-NO converter:

(1) *Instrument setup.* Follow the analyzer and NO₂-to-NO converter manufacturers' start-up and operating instructions. Adjust the analyzer and converter as needed to optimize performance.

(2) *Equipment setup.* Connect an ozonator's inlet to a zero-air or oxygen source and connect its outlet to one port of a 4-way cross fitting. Connect an NO span gas to another port. Connect the NO₂-to-NO converter inlet to another port, and connect an overflow vent line to the last port.

(3) *Adjustments.* Take the following steps to make adjustments:

(i) With the NO₂-to-NO converter in the bypass mode (*i.e.*, NO mode) and the ozonator off, adjust the NO and zero-gas flows so the NO concentration at the analyzer is at the peak total NO_x concentration expected during testing.

Verify that gas is flowing out of the overflow vent.

(ii) With the NO₂-to-NO converter still in the bypass mode, turn on the ozonator and adjust the ozonator so the NO concentration measured by the analyzer decreases by the same amount as maximum concentration of NO₂ expected during testing. This ensures that the ozonator is generating NO₂ at the maximum concentration expected during testing.

(4) *Data collection.* Maintain the ozonator adjustment in paragraph (d)(3) of this section, and keep the NO_x analyzer in the NO only mode (*i.e.*, bypass the NO₂-to-NO converter).

(i) Allow for stabilization, accounting only for transport delays and instrument response.

(ii) Calculate the mean of 30 seconds of sampled data from the analyzer and record this value as NO_{ref}.

(iii) Switch the analyzer to the total NO_x mode (that is, sample with the NO₂-to-NO converter) and allow for stabilization, accounting only for transport delays and instrument response.

(iv) Calculate the mean of 30 seconds of sampled data from the analyzer and record this value as NO_{xmeas}.

(v) Turn off the ozonator and allow for stabilization, accounting only for transport delays and instrument response.

(vi) Calculate the mean of 30 seconds of sampled data from the analyzer and record this value as NO_{xref}.

(5) *Performance evaluation.* Divide the quantity of (NO_{xmeas} - NO_{ref}) by the quantity of (NO_{xref} - NO_{ref}). If the result is less than 95%, repair or replace the NO₂-to-NO converter.

(e) *Exceptions.* The following exceptions apply:

(1) You may omit this verification if you can show by engineering analysis that for your NO_x sampling system and your emission calculations procedures, the converter always affects your brake-specific NO_x emission results by less than 0.5% of the applicable NO_x standard.

(2) You may use a converter that you determine does not meet this verification, as long as you try to correct the problem and the measurement deficiency does not adversely affect your ability to show that engines comply with all applicable emission standards.

PM Measurements

§ 1065.390 PM balance verifications and weighing process verification.

(a) *Scope and frequency.* This section describes three verifications. The first

verification requires an independent verification of PM balance performance, and this must be performed within 370 days before emission testing. The second verification requires zeroing and spanning the balance, and this must be performed within 12 h before weighing. The third verification requires comparing a current mass determination of pooled reference samples with the previous mass determination of the pooled reference samples. This verification must be performed within 12 h before weighing.

(b) *Independent verification.* Have the balance manufacturer (or a representative approved by the balance manufacturer) verify the balance performance within 370 days of testing.

(c) *Zeroing and spanning.* You must verify balance performance by zeroing and spanning it with at least one calibration weight, and any weights you use must meet the specifications in § 1065.790 to perform this verification.

(1) Use a manual procedure in which you zero the balance and span the balance with at least one calibration weight. If you normally use mean values by repeating the weighing process to improve the accuracy and precision of PM measurements, use the same process to verify balance performance.

(2) You may use an automated procedure to verify balance performance. For example many balances have internal calibration weights that are used automatically to verify balance performance. Note that if you use internal balance weights, the weights must meet the specifications in § 1065.790 to perform this verification.

(d) *Reference sample weighing.* You must also verify the PM-weighing environment and weighing process by weighing reference PM sample media. Repeated weighing of a reference mass must return the same value within ±10 µg or ±10% of the net PM mass expected at the standard (if known), whichever is higher. Perform this verification as follows:

(1) Keep at least two samples of unused PM sample media in the PM-stabilization environment. Use these as references. If you collect PM with filters, select unused filters of the same material and size for use as references. You may periodically replace references, using good engineering judgment.

(2) Stabilize references in the PM stabilization environment. Consider references stabilized if they have been in the PM-stabilization environment for a minimum of 30 min, and the PM-stabilization environment has been within the specifications of

§ 1065.190(d) for at least the preceding 60 min.

(3) Exercise the balance several times with a reference sample. We recommend weighing ten samples without recording the values.

(4) Zero and span the balance.

(5) Weigh each of the reference samples and record their masses. We recommend using substitution weighing as described in § 1065.590(j). If you normally use mean values by repeating the weighing process to improve the accuracy and precision of PM measurements, use the same process to measure reference masses.

(6) Record the balance environment dewpoint, ambient temperature, and atmospheric pressure.

(7) Use the recorded ambient conditions to correct results for buoyancy as described in § 1065.690. Record the buoyancy-corrected mass of each of the references.

(8) Subtract each of the reference's buoyancy-corrected masses from the most recent previous determinations of their masses.

(9) If the mean of the reference's masses changes by more than that allowed under paragraph (d) of this section, then invalidate all PM results that were determined between the two times that the reference masses were determined.

§ 1065.395 Inertial PM balance verifications.

This section describes how to verify the performance of an inertial PM balance.

(a) *Independent verification.* Have the balance manufacturer (or a representative approved by the balance manufacturer) verify the inertial balance performance within 370 days before testing.

(b) *Other verifications.* Perform other verifications using good engineering judgment and instrument manufacturer recommendations.

Subpart E—Engine Selection, Preparation, and Maintenance

§ 1065.401 Test engine selection.

While all engine configurations within a certified engine family must comply with the applicable standards in the standard-setting part, you need not test each configuration for certification.

(a) Select an engine configuration within the engine family for testing, as follows:

(1) Test the engine that we specify, whether we issue general guidance or give you specific instructions.

(2) If we do not tell you which engine to test, follow any instructions in the standard-setting part.

(3) If we do not tell you which engine to test and the standard-setting part does not include specifications for selecting test engines, use good engineering judgment to select the engine configuration within the engine family that is most likely to exceed an emission standard.

(b) In the absence of other information, the following characteristics are appropriate to consider when selecting the engine to test:

(1) Maximum fueling rates.

(2) Maximum loads.

(3) Maximum in-use speeds.

(4) Highest sales volume.

(c) For our testing, we may select any engine configuration within the engine family.

§ 1065.405 Test engine preparation and maintenance.

(a) If you are testing an emission-data engine for certification, make sure it is built to represent production engines. This includes governors that you normally install on production engines. If you do not install governors on production engines, simulate a governor that is representative of a governor that others will install on your production engines.

(b) Run the test engine, with all emission-control systems operating, long enough to stabilize emission levels. Unless otherwise specified in the standard-setting part, you may consider emission levels stable without measurement if you accumulate 12 h of operation for a spark-ignition engine or 125 h for a compression-ignition engine. If the engine needs more or less operation to stabilize emission levels, record your reasons and the methods for doing this, and give us these records if we ask for them. To ensure consistency between low-hour engines and deterioration factors, you must use the same stabilization procedures for all emission-data engines within an engine family.

(c) Record any maintenance, modifications, parts changes, diagnostic or emissions testing and document the need for each event. You must provide this information if we request it.

(d) For accumulating operating hours on your test engines, select engine operation that represents normal in-use operation for the engine family.

(e) If your engine will be used in a vehicle equipped with a canister for storing evaporative hydrocarbons for eventual combustion in the engine, attach a canister to the engine before running an emission test. You may request to omit using an evaporative canister during testing if you can show

that it would not affect your ability to show compliance with the applicable emission standards. You do not have to accumulate engine operation before emission testing with an installed canister. Prior to an emission test, use the following steps to attach a canister to your engine:

(1) Use a canister and plumbing arrangement that represents the in-use configuration of the largest capacity canister in all expected applications.

(2) Use a canister that is fully loaded with fuel vapors.

(3) Connect the canister's purge port to the engine.

(4) Plug the canister port that is normally connected to the fuel tank.

§ 1065.410 Maintenance limits for stabilized test engines.

(a) After you stabilize the test engine's emission levels, you may do maintenance as allowed by the standard-setting part. However, you may not do any maintenance based on emission measurements from the test engine (*i.e.*, unscheduled maintenance).

(b) For any critical emission-related maintenance—other than what we specifically allow in the standard-setting part—you must completely test an engine for emissions before and after doing any maintenance that might affect emissions, unless we waive this requirement.

(c) Keep a record of the inspection and update your application to document any changes as a result of the inspection. You may use equipment, instruments, or tools to identify bad engine components. Any equipment, instruments, or tools used for scheduled maintenance on emission data engines must be available to dealerships and other service outlets.

(d) You may adjust or repair an emission-data engine as long as you document these changes in your application.

(e) If we determine that a part failure, system malfunction, or associated repairs have made the engine's emission controls unrepresentative of production engines, you may no longer use it as an emission-data. Also, if your test engine has a major mechanical failure that requires you to take it apart, you may no longer use it as an emission-data engine.

§ 1065.415 Durability demonstration.

If the standard-setting part requires durability testing, you must accumulate service in a way that represents how you expect the engine to operate in use. You may accumulate service hours using an accelerated schedule, such as through continuous operation or by using duty cycles that are more aggressive than in-use operation.

(a) *Maintenance.* The following limits apply to the maintenance that we allow you to do on an emission-data engine:

(1) You may perform scheduled maintenance that you recommend to operators, but only if it is consistent with the standard-setting part's restrictions.

(2) You may perform additional maintenance only as specified in § 1065.410 or allowed by the standard-setting part.

(3) We may approve additional maintenance to your durability engine if all the following occur:

(i) Something clearly malfunctions—such as persistent misfire, engine stall, overheating, fluid leaks, or loss of oil pressure—and needs maintenance or repair.

(ii) You provide us an opportunity to verify the extent of the malfunction before you do the maintenance.

(b) *Emission measurements.* Perform emission tests following the provisions of the standard setting part and this part, as applicable. Perform emission tests to determine deterioration factors consistent with good engineering judgment. Evenly space any tests between the first and last test points throughout the durability period, unless we approve otherwise.

Subpart F—Performing an Emission Test in the Laboratory

§ 1065.501 Overview.

(a) Use the procedures detailed in this subpart to measure engine emissions in a laboratory setting. This section describes how to:

(1) Map your engine by recording specified speed and torque data, as measured from the engine's primary output shaft.

(2) Transform normalized duty cycles into reference duty cycles for your engine by using an engine map.

(3) Prepare your engine, equipment, and measurement instruments for an emission test.

(4) Perform pre-test procedures to verify proper operation of certain equipment and analyzers.

(5) Record pre-test data.

(6) Start or restart the engine and sampling systems.

(7) Sample emissions throughout the duty cycle.

(8) Record post-test data.

(9) Perform post-test procedures to verify proper operation of certain equipment and analyzers.

(10) Weigh PM samples.

(b) A laboratory emission test generally consists of measuring emissions and other parameters while an engine follows one or more duty

cycles that are specified in the standard-setting part. There are two general types of duty cycles:

(1) *Transient cycles.* Transient duty cycles are typically specified in the standard-setting part as a second-by-second sequence of speed commands and torque (or power) commands. Operate an engine over a transient cycle such that the speed and torque of the engine's primary output shaft follows the target values. Proportionally sample emissions and other parameters and use the calculations in subpart G of this part to calculate emissions. Start a transient test according to the standard-setting part, as follows:

(i) A cold-start transient cycle where you start to measure emissions just before starting a cold engine.

(ii) A hot-start transient cycle where you start to measure emissions just before starting a warmed-up engine.

(iii) A hot running transient cycle where you start to measure emissions after an engine is started, warmed up, and running.

(2) *Steady-state cycles.* Steady-state duty cycles are typically specified in the standard-setting part as a list of discrete operating points (modes), where each operating point has one value of a speed command and one value of a torque (or power) command. Ramped-modal cycles for steady-state testing also list test times for each mode and ramps of speed and torque to follow between modes. Start a steady-state cycle as a hot running test, where you start to measure emissions after an engine is started, warmed up and running. You may run a steady-state duty cycle as a discrete-mode cycle or a ramped-modal cycle, as follows:

(i) *Discrete-mode cycles.* Before emission sampling, stabilize an engine at the first discrete mode. Sample emissions and other parameters for that mode and then stop emission sampling. Record mean values for that mode, and then stabilize the engine at the next mode. Continue to sample each mode discretely and calculate weighted emission results according to the standard-setting part.

(ii) *Ramped-modal cycles.* Perform ramped-modal cycles similar to the way you would perform transient cycles, except that ramped-modal cycles involve mostly steady-state engine operation. Perform a ramped-modal cycle as a sequence of second-by-second speed commands and torque (or power) commands. Proportionally sample emissions and other parameters during the cycle and use the calculations in subpart G of this part to calculate emissions.

(c) Other subparts in this part identify how to select and prepare an engine for testing (subpart E), how to perform the required engine service accumulation (subpart E), and how to calculate emission results (subpart G).

(d) Subpart J of this part describes how to perform field testing.

§ 1065.510 Engine mapping.

(a) *Scope and frequency.* An engine map is a data set that consists of a series of paired data points that represent the maximum brake torque versus engine speed, measured at the engine's primary output shaft. Map your engine while it is connected to a dynamometer.

Configure any auxiliary work inputs and outputs such as hybrid, turbo-compounding, or thermoelectric systems to represent their in-use configurations, and use the same configuration for emission testing. See Figure 1 of § 1065.210. This may involve configuring initial states of charge and rates and times of auxiliary-work inputs and outputs. We recommend that you contact the Designated Compliance Officer before testing to determine how you should configure any auxiliary-work inputs and outputs. Use the most recent engine map to transform a normalized duty cycle from the standard-setting part to a reference duty cycle specific to your engine. Normalized duty cycles are specified in the standard-setting part. You may update an engine map at any time by repeating the engine-mapping procedure. You must map or re-map an engine before a test if any of the following apply:

(1) If you have not performed an initial engine map.

(2) If the atmospheric pressure near the engine's air inlet is not within ± 5 kPa of the atmospheric pressure recorded at the time of the last engine map.

(3) If the engine or emission-control system has undergone changes that might affect maximum torque performance. This includes changing the configuration of auxiliary work inputs and outputs.

(4) If you capture an incomplete map on your first attempt or you do not complete a map within the specified time tolerance. You may repeat mapping as often as necessary to capture a complete map within the specified time.

(b) *Mapping variable-speed engines.* Map variable-speed engines as follows:

(1) Record the atmospheric pressure.

(2) Warm up the engine by operating it. We recommend operating the engine at any speed and at approximately 75% of the its expected maximum power. Continue the warm-up until either the

engine coolant, block, or head absolute temperature is within $\pm 2\%$ of its mean value for at least 2 min or until the engine thermostat controls engine temperature.

(3) Operate the engine at its warm idle speed.

(4) Set operator demand to maximum and control engine speed at $(95 \pm 1)\%$ of its warm idle speed for at least 15 seconds. For engines with reference duty cycles whose lowest speed is greater than warm idle speed, you may start the map at $(95 \pm 1)\%$ of the lowest reference speed.

(5) Perform one of the following:

(i) For any engine subject only to steady-state duty cycles (*i.e.*, discrete-mode or ramped-modal), you may perform an engine map by using discrete speeds. Select at least 20 evenly spaced setpoints between warm idle and the highest speed above maximum mapped power at which $(50$ to $75)\%$ of maximum power occurs. If this highest speed is unsafe or unrepresentative (e.g. for ungoverned engines), use good engineering judgment to map up to the maximum safe speed or the maximum representative speed. At each setpoint, stabilize speed and allow torque to stabilize. Record the mean speed and torque at each setpoint. We recommend that you stabilize an engine for at least 15 seconds at each setpoint and record the mean feedback speed and torque of the last (4 to 6) seconds. Use linear interpolation to determine intermediate speeds and torques. Use this series of speeds and torques to generate the power map as described in paragraph (e) of this section.

(ii) For any variable-speed engine, you may perform an engine map by using a continuous sweep of speed by continuing to record the mean feedback speed and torque at 1 Hz or more frequently and increasing speed at a constant rate such that it takes (4 to 6) min to sweep from 95% of warm idle to the highest speed above maximum power at which $(50$ to $75)\%$ of maximum power occurs. If this highest speed is unsafe or unrepresentative (e.g. for ungoverned engines), use good engineering judgment to map up to the maximum safe speed or the maximum representative speed. Stop recording after you complete the sweep. From the series of mean speed and maximum torque values, use linear interpolation to determine intermediate values. Use this series of speeds and torques to generate the power map as described in paragraph (e) of this section.

(c) *Negative torque mapping.* If your engine is subject to a reference duty cycle that specifies negative torque

values, generate a motoring map by any of the following procedures:

(1) Multiply the positive torques from your map by -40% . Use linear interpolation to determine intermediate values.

(2) Map the amount of negative torque required to motor the engine by repeating paragraph (b) of this section with minimum operator demand.

(3) Determine the amount of negative torque required to motor the engine at the following two points: At warm idle and at the highest speed above maximum power at which $(50$ to $75)\%$ of maximum power occurs. If this highest speed is unsafe or unrepresentative (e.g. for ungoverned engines), use good engineering judgment to map up to the maximum safe speed or the maximum representative speed. Operate the engine at these two points at minimum operator demand. Use linear interpolation to determine intermediate values.

(d) *Mapping constant-speed engines.* For constant-speed engines, generate a map as follows:

(1) Record the atmospheric pressure.

(2) Warm up the engine by operating it. We recommend operating the engine at approximately 75% of the engine's expected maximum power. Continue the warm-up until either the engine coolant, block, or head absolute temperature is within $\pm 2\%$ of its mean value for at least 2 min or until the engine thermostat controls engine temperature.

(3) You may operate the engine with a production constant-speed governor or simulate a constant-speed governor by controlling engine speed with an operator demand control system described in § 1065.110. Use either isochronous or speed-droop governor operation, as appropriate.

(4) With the governor or simulated governor controlling speed using operator demand, operate the engine at no-load governed speed (at high speed, not low idle) for at least 15 seconds.

(5) Record at 1 Hz the mean of feedback speed and torque. Use the dynamometer to increase torque at a constant rate. Unless the standard-setting part specifies otherwise, complete the map such that it takes (2 to 4) min to sweep from no-load governed speed to the lowest speed below maximum mapped power at which the engine develops $(85-95)\%$ of maximum mapped power. You may map your engine to lower speeds. Stop recording after you complete the sweep. Use this series of speeds and torques to generate the power map as described in paragraph (e) of this section.

(e) *Power mapping.* For all engines, create a power-versus-speed map by transforming torque and speed values to corresponding power values. Use the mean values from the recorded map data. Do not use any interpolated values. Multiply each torque by its corresponding speed and apply the appropriate conversion factors to arrive at units of power (kW).

(f) *Measured and declared test speeds and torques.* You may use test speeds and torques that you declare instead of measured speeds and torques if you declare them before engine mapping and they meet the criteria in this paragraph (f). Otherwise, you must use measured speed and torque.

(1) *Measured speeds and torques.*

Determine the applicable measured speeds and torques according to § 1065.610:

(i) Measured maximum test speed for variable-speed engines.

(ii) Measured maximum test torque for constant-speed engines.

(iii) Measured "A", "B", and "C" speeds for steady-state tests.

(iv) Measured intermediate speed for steady-state tests.

(2) *Required declared speeds.* You must declare the following speeds:

(i) Warmed-up, low-idle speed for variable-speed engines. Declare this speed in a way that is representative of in-use operation. For example, if your engine is typically connected to an automatic transmission or a hydrostatic transmission, declare this speed at the idle speed at which your engine operates when the transmission is engaged.

(ii) Warmed-up, no-load, high-idle speed for constant-speed engines.

(3) *Optional declared speeds.* You may declare an enhanced idle speed according to § 1065.610. You may use a declared value for any of the following as long as the declared value is within $(97.5$ to $102.5)\%$ of its corresponding measured value:

(i) Measured maximum test speed for variable-speed engines.

(ii) Measured intermediate speed for steady-state tests.

(iii) Measured "A", "B", and "C" speeds for steady-state tests.

(4) *Declared torques.* You may declare an enhanced idle torque according to § 1065.610. You may declare maximum test torque as long as it is within $(95$ to $100)\%$ of the measured value.

(g) *Other mapping procedures.* You may use other mapping procedures if you believe the procedures specified in this section are unsafe or unrepresentative for your engine. Any alternate techniques must satisfy the intent of the specified mapping

procedures, which is to determine the maximum available torque at all engine speeds that occur during a duty cycle. Report any deviations from this section's mapping procedures.

§ 1065.512 Duty cycle generation.

(a) The standard-setting part defines applicable duty cycles in a normalized format. A normalized duty cycle consists of a sequence of paired values for speed and torque or for speed and power.

(b) Transform normalized values of speed, torque, and power using the following conventions:

(1) *Engine speed for variable-speed engines.* For variable-speed engines, normalized speed may be expressed as a percentage between idle speed and maximum test speed, f_{ntest} , or speed may be expressed by referring to a defined speed by name, such as warm idle," "intermediate speed," or "A," "B," or "C" speed. Section 1065.610 describes how to transform these normalized values into a sequence of reference speeds, f_{nref} . Note that the cycle-validation criteria in § 1065.514 allow an engine to govern itself at its in-use idle speed. This allowance permits you to test engines with enhanced-idle devices and to simulate the effects of transmissions such as automatic transmissions.

(2) *Engine torque for variable-speed engines.* For variable-speed engines, normalized torque is expressed as a percentage of the mapped torque at the corresponding reference speed. Section 1065.610 describes how to transform normalized torques into a sequence of reference torques, T_{ref} . Section 1065.610 also describes under what conditions you may command T_{ref} greater than the reference torque you calculated from a normalized duty cycle. This provision permits you to command T_{ref} values representing curb-idle transmission torque (CITT).

(3) *Engine torque for constant-speed engines.* For constant-speed engines, normalized torque is expressed as a percentage of maximum test torque, T_{test} . Section 1065.610 describes how to transform normalized torques into a sequence of reference torques, T_{ref} . Section 1065.610 also describes under what conditions you may command T_{ref} greater than 0 N·m when a normalized duty cycle specifies a 0% torque command.

(4) *Engine power.* For all engines, normalized power is expressed as a percentage of mapped power at maximum test speed, f_{ntest} . Section 1065.610 describes how to transform these normalized values into a sequence of reference powers, P_{ref} . You may convert these reference powers to reference speeds and torques for operator demand and dynamometer control.

(c) For variable-speed engines, command reference speeds and torques sequentially to perform a duty cycle. Issue speed and torque commands at a frequency of at least 5 Hz for transient cycles and at least 1 Hz for steady-state cycles (*i.e.*, discrete-mode and ramped-modal). For transient cycles, linearly interpolate between the 1 Hz reference values specified in the standard-setting part to determine the 5 Hz reference speeds and torques. During an emission test, record the 1 Hz mean values of the reference speeds and torques and the feedback speeds and torques. Use these recorded values to calculate cycle-validation statistics and total work.

(d) For constant-speed engines, operate the engine with the same production governor you used to map the engine in § 1065.525 or simulate the in-use operation of a governor the same way you simulated it to map the engine in § 1065.525. Command reference torque values sequentially to perform a duty cycle. Issue torque commands at a frequency of at least 5 Hz for transient cycles and at least 1 Hz for steady-state cycles (*i.e.*, discrete-mode, ramped-modal). For transient cycles, linearly interpolate between the 1 Hz reference values specified in the standard-setting part to determine the 5 Hz reference torque values. During an emission test, record the 1 Hz mean values of the reference torques and the feedback speeds and torques. Use these recorded values to calculate cycle-validation statistics and total work.

(e) You may perform practice duty cycles with the test engine to optimize operator demand and dynamometer controls to meet the cycle-validation criteria specified in § 1065.514.

§ 1065.514 Cycle-validation criteria.

This section describes how to determine if the engine's operation during the test adequately matched the reference duty cycle. This section

applies only to speed, torque, and power from the engine's primary output shaft. Other work inputs and outputs are not subject to cycle-validation criteria. For any data required in this section, use the duty cycle reference and feedback values that you recorded during a test interval.

(a) *Testing performed by EPA.* Our tests must meet the specifications of paragraph (g) of this section, unless we determine that failing to meet the specifications is related to engine performance rather than to shortcomings of the dynamometer or other laboratory equipment.

(b) *Testing performed by manufacturers.* Emission tests that meet the specifications of paragraph (g) of this section satisfy the standard-setting part's requirements for duty cycles. You may ask to use a dynamometer or other laboratory equipment that cannot meet those specifications. We will approve your request as long as using the alternate equipment does not affect your ability to show compliance with the applicable emission standards.

(c) *Time-alignment.* Because time lag between feedback values and the reference values may bias cycle-validation results, you may advance or delay the entire sequence of feedback engine speed and torque pairs to synchronize them with the reference sequence.

(d) *Calculating work.* Before calculating work values, omit any points recorded during engine cranking and starting. Cranking and starting includes any time when an engine starter is engaged, any time when the engine is motored with a dynamometer for the sole purpose of starting the engine, and any time during operation before reaching idle speed. See § 1065.525(a) and (b) for more information about engine cranking. After omitting points recorded during engine cranking and starting, but before omitting any points under paragraph (e) of this section, calculate total work, W , based on the feedback values and reference work, W_{ref} , based on the reference values, as described in § 1065.650.

(e) *Omitting additional points.* Besides engine cranking, you may omit additional points from cycle-validation statistics as described in the following table:

TABLE 1 OF § 1065.514.—PERMISSIBLE CRITERIA FOR OMITTING POINTS FROM DUTY-CYCLE REGRESSION STATISTICS

When operator demands at its . . .	you may omit. . .	if. . .
For reference duty cycles that are specified in terms of speed and torque (f_{nref} , T_{ref}).		
minimum	power and torque	$T_{ref} < 0\%$ (motoring).
minimum	power and speed	$f_{nref} = 0\%$ (idle) and $T_{ref} = 0\%$ (idle) and $T_{ref} - (2\% \cdot T_{max\ mapped}) < T < T_{ref} + (2\% \cdot T_{max\ mapped})$.
minimum	power and either torque or speed	$f_n > f_{nref}$ or $T > T_{ref}$ but not if $f_n > f_{nref}$ and $T > T_{ref}$.
maximum	power and either torque or speed	$f_n < f_{nref}$ or $T < T_{ref}$ but not if $f_n < f_{nref}$ and $T < T_{ref}$.
For reference duty cycles that are specified in terms of speed and power (f_{nref} , P_{ref}).		
minimum	power and torque	$P_{ref} < 0\%$ (motoring).
minimum	power and speed	$f_{nref} = 0\%$ (idle) and $P_{ref} = 0\%$ (idle) and $P_{ref} - (2\% \cdot P_{max\ mapped}) < P < P_{ref} + (2\% \cdot P_{max\ mapped})$.
minimum	power and either torque or speed	$f_n > f_{nref}$ or $P > P_{ref}$ but not if $f_n > f_{nref}$ and $P > P_{ref}$.
maximum	power and either torque or speed	$f_n < f_{nref}$ or $P < P_{ref}$ but not if $f_n < f_{nref}$ and $P < P_{ref}$.

(f) *Statistical parameters.* Use the remaining points to calculate regression statistics described in § 1065.602. Round calculated regression statistics to the same number of significant digits as the criteria to which they are compared. Refer to Table 2 of § 1065.514 for the criteria. Calculate the following regression statistics :

- (1) Slopes for feedback speed, a_{1fn} , feedback torque, a_{1T} , and feedback power a_{1P} .
- (2) Intercepts for feedback speed, a_{0fn} , feedback torque, a_{0T} , and feedback power a_{0P} .
- (3) Standard estimates of error for feedback speed, SEE_{fn} , feedback torque, SE_{T} , and feedback power SEE_{P} .
- (4) Coefficients of determination for feedback speed, r^2_{fn} , feedback torque, r^2_{T} , and feedback power r^2_{P} .

(g) *Cycle-validation criteria.* Unless the standard-setting part specifies otherwise, use the following criteria to validate a duty cycle:

- (1) For variable-speed engines, apply all the statistical criteria in Table 2 of this section.
- (2) For constant-speed engines, apply only the statistical criteria for torque in the Table 2 of this section.

TABLE 2 OF § 1065.514.—DEFAULT STATISTICAL CRITERIA FOR VALIDATING DUTY CYCLES

Parameter	Speed	Torque	Power
Slope, a_1	$0.950 \leq a_1 < 1.030$	$0.830 \leq a_1 < 1.030$	$0.830 \leq a_1 < 1.030$.
Absolute value of intercept, $ a_0 $	$\leq 10\%$ of warm idle	$\leq 2.0\%$ of maximum mapped torque.	$\leq 2.0\%$ of maximum mapped power.
Standard error of estimate, SEE ...	$\leq 5.0\%$ of maximum test speed ...	$\leq 10\%$ of maximum mapped torque.	$\leq 10\%$ of maximum mapped power.
Coefficient of determination, r^2	≥ 0.970	≥ 0.850	≥ 0.910 .

§ 1065.520 Pre-test verification procedures and pre-test data collection.

(a) If your engine must comply with a PM standard, follow the procedures for PM sample preconditioning and tare weighing according to § 1065.590.

(b) Unless the standard-setting part specifies different values, verify that ambient conditions are within the following tolerances before the test:

- (1) Ambient temperature of (20 to 30) °C.
- (2) Atmospheric pressure of (80.000 to 103.325) kPa and within $\pm 5\%$ of the value recorded at the time of the last engine map.
- (3) Dilution air as specified in § 1065.140(b).

(c) You may test engines at any intake-air humidity, and we may test engines at any intake-air humidity.

(d) Verify that auxiliary-work inputs and outputs are configured as they were

during engine mapping, as described in § 1065.510(a).

(e) You may perform a final calibration of the speed, torque, and proportional-flow control systems, which may include performing practice duty cycles.

(f) You may perform the following recommended procedure to precondition sampling systems:

- (1) Start the engine and use good engineering judgment to bring it to 100% torque at any speed above its peak-torque speed.
- (2) Operate any dilution systems at their expected flow rates. Prevent aqueous condensation in the dilution systems.
- (3) Operate any PM sampling systems at their expected flow rates.
- (4) Sample PM for at least 10 min using any sample media. You may change sample media during preconditioning. You may discard

preconditioning samples without weighing them.

(5) You may purge any gaseous sampling systems during preconditioning.

(6) You may conduct calibrations or verifications on any idle equipment or analyzers during preconditioning.

(7) Proceed with the test sequence described in § 1065.530(a)(1).

(g) After the last practice or preconditioning cycle before an emission test, verify the amount of contamination in the HC sampling system as follows:

- (1) Select the HC analyzer range for measuring the flow-weighted mean concentration expected at the HC standard.
- (2) Zero the HC analyzer at the analyzer zero or sample port. Note that FID zero and span balance gases may be any combination of purified air or purified nitrogen that meets the

specifications of § 1065.750. We recommend FID analyzer zero and span gases that contain approximately the flow-weighted mean concentration of O₂ expected during testing.

(3) Span the HC analyzer using span gas introduced at the analyzer span or sample port. Span on a carbon number basis of one (C₁). For example, if you use a C₃H₈ span gas of concentration 200 µmol/mol, span the FID to respond with a value of 600 µmol/mol.

(4) Overflow zero gas at the HC probe or into a fitting between the HC probe and its transfer line.

(5) Measure the HC concentration in the sampling system, as follows:

(i) For continuous sampling, record the mean HC concentration as overflow zero air flows.

(ii) For batch sampling, fill the sample medium and record its mean HC concentration.

(6) Record this value as the initial HC concentration, X_{HCinit}, and use it to correct measured values as described in § 1065.660.

(7) If X_{HCinit} exceeds the greatest of the following values, determine the source of the contamination and take corrective action, such as purging the system during an additional preconditioning cycle or replacing contaminated portions:

(i) 2% of the flow-weighted mean concentration expected at the standard.

(ii) 2% of the flow-weighted mean concentration measured during testing.

(iii) For any compression-ignition engines, any two-stroke spark ignition engines, or 4-stroke spark-ignition engines that are less than 19 kW, 2 µmol/mol.

(8) If corrective action does not resolve the deficiency, you may request to use the contaminated system as an alternate procedure under § 1065.10.

§ 1065.525 Engine starting, restarting, and shutdown.

(a) Start the engine using one of the following methods:

(1) Start the engine as recommended in the owners manual using a production starter motor and adequately charged battery or a suitable power supply.

(2) Use the dynamometer to start the engine. To do this, motor the engine within ±25% of its typical in-use cranking speed. Stop cranking within 1 second of starting the engine.

(b) If the engine does not start after 15 seconds of cranking, stop cranking and determine why the engine failed to start, unless the owners manual or the service-repair manual describes the longer cranking time as normal.

(c) Respond to engine stalling with the following steps:

(1) If the engine stalls during warm-up before emission sampling begins, restart the engine and continue warm-up.

(2) If the engine stalls during preconditioning before emission sampling begins, restart the engine and restart the preconditioning sequence.

(3) If the engine stalls at any time after emission sampling begins for a transient test or ramped-modal cycle test, the test is void.

(4) If the engine stalls at any time after emission sampling begins for a discrete mode in a discrete-mode duty cycle test, void the test or perform the following steps to continue the test:

(i) Restart the engine.

(ii) Use good engineering judgment to restart the test sequence using the appropriate steps in § 1065.530(b)

(iii) Precondition the engine at the previous discrete mode for a similar amount of time compared with how long it was initially run.

(iv) Advance to the mode at which the engine stalled and continue with the duty cycle as specified in the standard-setting part.

(v) Complete the remainder of the test according to the requirements in this subpart.

(d) Shut down the engine according to the manufacturer's specifications.

§ 1065.530 Emission test sequence.

(a) Time the start of testing as follows:

(1) Perform one of the following if you precondition sampling systems as described in § 1065.520(f):

(i) For cold-start duty cycles, shut down the engine. Unless the standard-setting part specifies that you may only perform a natural engine cooldown, you may perform a forced engine cooldown. Use good engineering judgment to set up systems to send cooling air across the engine, to send cool oil through the engine lubrication system, to remove heat from coolant through the engine cooling system, and to remove heat from an exhaust aftertreatment system. In the case of a forced aftertreatment cooldown, good engineering judgment would indicate that you not start flowing cooling air until the aftertreatment system has cooled below its catalytic activation temperature. For platinum-group metal catalysts, this temperature is about 200 °C. Once the aftertreatment system has naturally cooled below its catalytic activation temperature, good engineering judgment would indicate that you use clean air with a temperature of at least 15 °C, and direct the air through the aftertreatment system in the normal direction of exhaust flow. Do not use any cooling procedure that results in

unrepresentative emissions (see § 1065.10(c)(1)). You may start a cold-start duty cycle when the temperatures of an engine's lubricant, coolant, and aftertreatment systems are all between (20 and 30) °C.

(ii) For hot-start emission measurements, shut down the engine. Start a hot-start duty cycle within 20 min of engine shutdown.

(iii) For testing that involves hot-stabilized emission measurements, such as any steady-state testing, you may continue to operate the engine at f_{intest} and 100% torque if that is the first operating point. Otherwise, operate the engine at warm, idle or the first operating point of the duty cycle. In any case, start the emission test within 10 min after you complete the preconditioning procedure.

(2) For all other testing, perform one of the following:

(i) For cold-start duty cycles, prepare the engine according to paragraph (a)(1)(i) of this section.

(ii) For hot-start emission measurements, first operate the engine at any speed above peak-torque speed and at (65 to 85) % of maximum mapped power until either the engine coolant, block, or head absolute temperature is within ±2% of its mean value for at least 2 min or until the engine thermostat controls engine temperature. Shut down the engine. Start the duty cycle within 20 min of engine shutdown.

(iii) For testing that involves hot-stabilized emission measurements, bring the engine either to warm idle or the first operating point of the duty cycle. Start the test within 10 min of achieving temperature stability. Determine temperature stability either as the point at which the engine coolant, block, or head absolute temperature is within ±2% of its mean value for at least 2 min, or as the point at which the engine thermostat controls engine temperature.

(b) Take the following steps before emission sampling begins:

(1) For batch sampling, connect clean storage media, such as evacuated bags or tare-weighted filters.

(2) Start all measurement instruments according to the instrument manufacturer's instructions and using good engineering judgment.

(3) Start dilution systems, sample pumps, cooling fans, and the data-collection system.

(4) Pre-heat or pre-cool heat exchangers in the sampling system to within their operating temperature tolerances for a test.

(5) Allow heated or cooled components such as sample lines,

filters, chillers, and pumps to stabilize at their operating temperatures.

(6) Verify that there are no significant vacuum-side leaks according to § 1065.345.

(7) Adjust the sample flow rates to desired levels, using bypass flow, if desired.

(8) Zero or re-zero any electronic integrating devices, before the start of any test interval.

(9) Select gas analyzer ranges. You may use analyzers that automatically switch ranges during a test only if switching is performed by changing the span over which the digital resolution of the instrument is applied. During a test you may not switch the gains of an analyzer's analog operational amplifier(s).

(10) Zero and span all continuous analyzers using NIST-traceable gases that meet the specifications of § 1065.750. Span FID analyzers on a carbon number basis of one (1), C₁. For example, if you use a C₃H₈ span gas of concentration 200 µmol/mol, span the FID to respond with a value of 600 µmol/mol.

(11) We recommend that you verify gas analyzer response after zeroing and spanning by flowing a calibration gas that has a concentration near one-half of the span gas concentration. Based on the results and good engineering judgment, you may decide whether or not to re-zero, re-span, or re-calibrate a gas analyzer before starting a test.

(12) If you correct for dilution air background concentrations of engine exhaust constituents, start measuring and recording background concentrations.

(c) Start testing as follows:

(1) If an engine is already running and warmed up, and starting is not part of the duty cycle, perform the following for the various duty cycles.

(i) *Transient and steady-state ramped-modal cycles.* Simultaneously start running the duty cycle, sampling exhaust gases, recording data, and integrating measured values.

(ii) *Steady-state discrete-mode cycles.* Control speed and torque to the first mode in the test cycle. Follow the instructions in the standard-setting part to determine how long to stabilize engine operation at each mode and how long to sample emissions at each mode.

(2) If engine starting is part of the duty cycle, initiate data logging, sampling of exhaust gases, and integrating measured values before attempting to start the engine. Initiate the duty cycle when the engine starts.

(d) At the end of the test interval, continue to operate all sampling and dilution systems to allow the sampling

system's response time to elapse. Then stop all sampling and recording, including the recording of background samples. Finally, stop any integrating devices and indicate the end of the duty cycle in the recorded data.

(e) Shut down the engine if you have completed testing or if it is part of the duty cycle.

(f) If testing involves another duty cycle after a soak period with the engine off, start a timer when the engine shuts down, and repeat the steps in paragraphs (b) through (e) of this section as needed.

(g) Take the following steps after emission sampling is complete:

(1) For any proportional batch sample, such as a bag sample or PM sample, verify that proportional sampling was maintained according to § 1065.545. Void any samples that did not maintain proportional sampling according to § 1065.545.

(2) Place any used PM samples into covered or sealed containers and return them to the PM-stabilization environment. Follow the PM sample post-conditioning and total weighing procedures in § 1065.595.

(3) As soon as practical after the duty cycle is complete but no later than 30 minutes after the duty cycle is complete, perform the following:

(i) Zero and span all batch gas analyzers.

(ii) Analyze any gaseous batch samples, including background samples.

(4) After quantifying exhaust gases, verify drift as follows:

(i) For batch and continuous gas analyzers, record the mean analyzer value after stabilizing a zero gas to the analyzer. Stabilization may include time to purge the analyzer of any sample gas, plus any additional time to account for analyzer response.

(ii) Record the mean analyzer value after stabilizing the span gas to the analyzer. Stabilization may include time to purge the analyzer of any sample gas, plus any additional time to account for analyzer response.

(iii) Use these data to validate and correct for drift as described in § 1065.550.

(h) Determine whether or not the test meets the cycle-validation criteria in § 1065.514.

(1) If the criteria void the test, you may retest using the same denormalized duty cycle, or you may re-map the engine, denormalize the reference duty cycle based on the new map and retest the engine using the new denormalized duty cycle.

(2) If the criteria void the test for a constant-speed engine only during

commands of maximum test torque, you may do the following:

(i) Determine the first and last feedback speeds at which maximum test torque was commanded.

(ii) If the last speed is greater than or equal to 90% of the first speed, the test is void. You may retest using the same denormalized duty cycle, or you may re-map the engine, denormalize the reference duty cycle based on the new map and retest the engine using the new denormalized duty cycle.

(iii) If the last speed is less than 90% of the first speed, reduce maximum test torque by 5%, and proceed as follows:

(A) Denormalize the entire duty cycle based on the reduced maximum test torque according to § 1065.512.

(B) Retest the engine using the denormalized test cycle that is based on the reduced maximum test torque.

(C) If your engine still fails the cycle criteria, reduce the maximum test torque by another 5% of the original maximum test torque.

(D) If your engine fails after repeating this procedure four times, such that your engine still fails after you have reduced the maximum test torque by 20% of the original maximum test torque, notify us and we will consider specifying a more appropriate duty cycle for your engine under the provisions of § 1065.10(c).

§ 1065.545 Validation of proportional flow control for batch sampling.

For any proportional batch sample such as a bag or PM filter, demonstrate that proportional sampling was maintained using one of the following, noting that you may omit up to 5% of the total number of data points as outliers:

(a) For any pair of flow meters, use the 1 Hz (or more frequently) recorded sample and total flow rates with the statistical calculations in § 1065.602. Determine the standard error of the estimate, SEE, of the sample flow rate versus the total flow rate. For each test interval, demonstrate that SEE was less than or equal to 3.5% of the mean sample flow rate.

(b) For any pair of flow meters, use the 1 Hz (or more frequently) recorded sample and total flow rates to demonstrate that each flow rate was constant within ±2.5% of its respective mean or target flow rate. You may use the following options instead of recording the respective flow rate of each type of meter:

(1) *Critical-flow venturi option.* For critical-flow venturis, you may use the 1 Hz (or more frequently) recorded venturi-inlet conditions. Demonstrate that the flow density at the venturi inlet

was constant within $\pm 2.5\%$ of the mean or target density over each test interval. For a CVS critical-flow venturi, you may demonstrate this by showing that the absolute temperature at the venturi inlet was constant within $\pm 4\%$ of the mean or target absolute temperature over each test interval.

(2) *Positive-displacement pump option.* You may use the 1 Hz (or more frequently) recorded pump-inlet conditions. Demonstrate that the density at the pump inlet was constant within $\pm 2.5\%$ of the mean or target density over each test interval. For a CVS pump, you may demonstrate this by showing that the absolute temperature at the pump inlet was constant within $\pm 2\%$ of the mean or target absolute temperature over each test interval.

(c) Using good engineering judgment, demonstrate with an engineering analysis that the proportional-flow control system inherently ensures proportional sampling under all circumstances expected during testing. For example, you might use CFVs for both sample flow and total flow and demonstrate that they always have the same inlet pressures and temperatures and that they always operate under critical-flow conditions.

§ 1065.550 Gas analyzer range validation, drift validation, and drift correction.

(a) *Range validation.* If an analyzer operated above 100% of its range at any time during the test, perform the following steps:

(1) For batch sampling, re-analyze the sample using the lowest analyzer range that results in a maximum instrument response below 100%. Report the result from the lowest range from which the analyzer operates below 100% of its range for the entire test.

(2) For continuous sampling, repeat the entire test using the next higher analyzer range. If the analyzer again operates above 100% of its range, repeat the test using the next higher range. Continue to repeat the test until the analyzer operates at less than 100% of its range for the entire test.

(b) *Drift validation and drift correction.* Calculate two sets of brake-specific emission results. Calculate one set using the data before drift correction and the other set after correcting all the data for drift according to § 1065.672. Use the two sets of brake-specific emission results as follows:

(1) If the difference between the corrected and uncorrected brake-specific emissions are within $\pm 4\%$ of the uncorrected results for all regulated emissions, the test is validated for drift. If not, the entire test is void.

(2) If the test is validated for drift, you must use only the drift-corrected emission results when reporting emissions, unless you demonstrate to us that using the drift-corrected results adversely affects your ability to demonstrate whether or not your engine complies with the applicable standards.

§ 1065.590 PM sample preconditioning and tare weighing.

Before an emission test, take the following steps to prepare PM samples and equipment for PM measurements:

(a) Make sure the balance and PM-stabilization environments meet the periodic verifications in § 1065.390.

(b) Visually inspect unused sample media (such as filters) for defects.

(c) To handle PM samples, use electrically grounded tweezers or a grounding strap, as described in § 1065.190.

(d) Place unused sample media in one or more containers that are open to the PM-stabilization environment. If you are using filters, you may place them in the bottom half of a filter cassette.

(e) Stabilize sample media in the PM-stabilization environment. Consider an unused sample medium stabilized as long as it has been in the PM-stabilization environment for a minimum of 30 min, during which the PM-stabilization environment has been within the specifications of § 1065.190.

(f) Weigh the sample media automatically or manually, as follows:

(1) For automatic weighing, follow the automation system manufacturer's instructions to prepare samples for weighing. This may include placing the samples in a special container.

(2) For manual weighing, use good engineering judgment to determine if substitution weighing is necessary to show that an engine meets the applicable standard. You may follow the substitution weighing procedure in paragraph (j) of this section, or you may develop your own procedure.

(g) Correct the measured weight for buoyancy as described in § 1065.690. These buoyancy-corrected values are the tare masses of the PM samples.

(h) You may repeat measurements to determine mean masses. Use good engineering judgment to exclude outliers and calculate mean mass values.

(i) If you use filters as sample media, load unused filters that have been tare-weighed into clean filter cassettes and place the loaded cassettes in a covered or sealed container before taking them to the test cell for sampling. We recommend that you keep filter cassettes clean by periodically washing or wiping them with a compatible

solvent applied using a lint-free cloth. Depending upon your cassette material, ethanol (C_2H_5OH) might be an acceptable solvent. Your cleaning frequency will depend on your engine's level of PM and HC emissions.

(j) Substitution weighing involves measurement of a reference weight before and after each weighing of a PM sample. While substitution weighing requires more measurements, it corrects for a balance's zero-drift and it relies on balance linearity only over a small range. This is most advantageous when quantifying net PM masses that are less than 0.1% of the sample medium's mass. However, it may not be advantageous when net PM masses exceed 1% of the sample medium's mass. The following steps are an example of substitution weighing:

(1) Use electrically grounded tweezers or a grounding strap, as described in § 1065.190.

(2) Use a static neutralizer as described in § 1065.190 to minimize static electric charge on any object before it is placed on the balance pan.

(3) Place on the balance pan a metal calibration weight that has a similar mass to that of the sample medium and meets the specifications for calibration weights in § 1065.790. If you use filters, the weight's mass should be about (80 to 100) mg for typical 47 mm diameter filters.

(4) Record the stable balance reading, then remove the calibration weight.

(5) Weigh an unused sample, record the stable balance reading and record the balance environment's dewpoint, ambient temperature, and atmospheric pressure.

(6) Reweigh the calibration weight and record the stable balance reading.

(7) Calculate the arithmetic mean of the two calibration-weight readings that you recorded immediately before and after weighing the unused sample. Subtract that mean value from the unused sample reading, then add the true mass of the calibration weight as stated on the calibration-weight certificate. Record this result. This is the unused sample's tare weight without correcting for buoyancy.

(8) Repeat these substitution-weighing steps for the remainder of your unused sample media.

(9) Follow the instructions given in paragraphs (g) through (i) of this section.

§ 1065.595 PM sample post-conditioning and total weighing.

(a) Make sure the weighing and PM-stabilization environments have met the periodic verifications in § 1065.390.

(b) In the PM-stabilization environment, remove PM samples from

sealed containers. If you use filters, you may remove them from their cassettes before or after stabilization. When you remove a filter from a cassette, separate the top half of the cassette from the bottom half using a cassette separator designed for this purpose.

(c) To handle PM samples, use electrically grounded tweezers or a grounding strap, as described in § 1065.190.

(d) Visually inspect PM samples. If PM ever contacts the transport container, cassette assembly, filter-separator tool, tweezers, static neutralizer, balance, or any other surface, void the measurements associated with that sample and clean the surface it contacted.

(e) To stabilize PM samples, place them in one or more containers that are open to the PM-stabilization environment, which is described in § 1065.190. A PM sample is stabilized as long as it has been in the PM-stabilization environment for one of the following durations, during which the stabilization environment has been within the specifications of § 1065.190:

(1) If you expect that a filter's total surface concentration of PM will be greater than about 0.473 mm/mm², expose the filter to the stabilization environment for at least 60 minutes before weighing.

(2) If you expect that a filter's total surface concentration of PM will be less than about 0.473 mm/mm², expose the filter to the stabilization environment for at least 30 minutes before weighing.

(3) If you are unsure of a filter's total surface concentration of PM, expose the filter to the stabilization environment for at least 60 minutes before weighing.

(f) Repeat the procedures in § 1065.590(f) through (i) to weigh used PM samples. Refer to a sample's post-test mass, after correcting for buoyancy, as its total mass.

(g) Subtract each buoyancy-corrected tare mass from its respective buoyancy-corrected total mass. The result is the net PM mass, m_{PM}. Use m_{PM} in emission calculations in § 1065.650.

Subpart G—Calculations and Data Requirements

§ 1065.601 Overview.

(a) This subpart describes how to—

(1) Use the signals recorded before, during, and after an emission test to calculate brake-specific emissions of each regulated constituent.

(2) Perform calculations for calibrations and performance checks.

(3) Determine statistical values.

(b) You may use data from multiple systems to calculate test results for a single emission test, consistent with good engineering judgment. You may not use test results from multiple emission tests to report emissions. We allow weighted means where appropriate. You may discard statistical outliers, but you must report all results.

(c) You may use any of the following calculations instead of the calculations specified in this subpart G:

(1) Mass-based emission calculations prescribed by the International Organization for Standardization (ISO), according to ISO 8178.

(2) Other calculations that you show are equivalent to within ±0.1% of the brake-specific emission results determined using the calculations specified in this subpart G.

§ 1065.602 Statistics.

(a) *Overview.* This section contains equations and example calculations for statistics that are specified in this part. In this section we use the letter “y” to denote a generic measured quantity, the superscript over-bar “[̄]” to denote an arithmetic mean, and the subscript “_{ref}” to denote the reference quantity being measured.

(b) *Arithmetic mean.* Calculate an arithmetic mean, \bar{y} , as follows:

$$\bar{y} = \frac{\sum_{i=1}^{10} y_i}{N} \quad \text{Eq. 1065.602-1}$$

Example:

N = 3
 y₁ = 10.60
 y₂ = 11.91
 y_N = y₃ = 11.09

$$\bar{y} = \frac{10.60 + 11.91 + 11.09}{3}$$

$\bar{y} \leq 11.20$

(c) *Standard deviation.* Calculate the standard deviation for a non-biased (e.g., N-1) sample, σ , as follows:

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^N (y_i - \bar{y})^2}{(N-1)}} \quad \text{Eq. 1065.602-2}$$

Example:

N = 3
 y₁ = 10.60
 y₂ = 11.91
 y_N = y₃ = 11.09
 $\bar{y} \leq 11.20$

$$\sigma_y = \sqrt{\frac{(10.60 - 11.2)^2 + (11.91 - 11.2)^2 + (11.09 - 11.2)^2}{2}}$$

$\sigma_y = 0.6619$

(d) *Root mean square.* Calculate a root mean square, rms_y, as follows:

$$\text{rms}_y = \sqrt{\frac{1}{N} \sum_{i=1}^N y_i^2} \quad \text{Eq. 1065.602-3}$$

Example:

N = 3
 y₁ = 10.60
 y₂ = 11.91
 y_N = y₃ = 11.09

$$\text{rms}_y = \sqrt{\frac{10.60^2 + 11.91^2 + 11.09^2}{3}}$$

rms_y = 11.21

(e) *Accuracy.* Calculate an accuracy, as follows, noting that the are arithmetic means, each determined by repeatedly measuring one sample of a single reference quantity, y_{ref}:

$$\text{accuracy} = |y_{\text{ref}} - \bar{y}| \quad \text{Eq. 1065.602-4}$$

Example:

y_{ref} = 1800.0
 N = 10

$$\bar{y} = \frac{\sum_{i=1}^{10} \bar{y}_i}{10} = 1802.5$$

accuracy = |1800.0 - 1802.5|

accuracy = 2.5

(f) *t-test.* Determine if your data passes a t-test by using the following equations and tables:

(1) For an unpaired t-test, calculate the t statistic and its number of degrees of freedom, v, as follows:

$$t = \frac{|\bar{y}_{\text{ref}} - \bar{y}|}{\sqrt{\frac{\sigma_{\text{ref}}^2}{N_{\text{ref}}} + \frac{\sigma_y^2}{N}}} \quad \text{Eq. 1065.602-5}$$